NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

OODA LOOP 2.0: A MODEL FOR COMPETITION AND EXPEDITIONARY ADVANCED BASE OPERATIONS

by

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June 2021

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2021	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE OODA LOOP 2.0: A MODEL FOR COMPETITION AND EXPEDITIONARY ADVANCED BASE OPERATIONS			**5. FUNDING NUMBERS**
6. AUTHOR(S) Michael D. Kennedy			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

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14. SUBJECT TERMS			**15. NUMBER OF PAGES**
command and control, C4I, C2, Boyd, OODA Loop, Dynamic Model of Situated Cognition, DMSC, expeditionary advanced base operations, EABO, situational awareness, SA			113
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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OODA LOOP 2.0: A MODEL FOR COMPETITION AND EXPEDITIONARY ADVANCED BASE OPERATIONS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY (COMMAND, CONTROL, AND COMMUNICATIONS)

from the

NAVAL POSTGRADUATE SCHOOL
June 2021

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ABSTRACT

The character of modern warfare is shifting toward one of competition with peer adversaries, and it is important that command and control models and concepts are adapting as well. Given that the Marine Corps' command and control doctrine is based primarily on the theories of John Boyd, it is important to examine how the observe-orient-decide-act (OODA) loop can be augmented and modified in order to account for the impact of technological systems. This thesis examines decision-making theories, command and control doctrine and theories, and the operational environment in order to develop a modified OODA loop that can benefit tactical decision-making while executing expeditionary advanced base operations (EABO). This research used the updated OODA loop to examine two vignettes based on EABO concepts of employment in order to identify command and control challenges during normal operations and in a denied or degraded information environment.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	anti-access/area denial
AI	artificial intelligence
AIS	automatic information system
AMD	air and missile defense
AMDC	Air and Missile Defense Commander
ASBM	anti-ship ballistic missile
ASCM	anti-ship cruise missile
C2	command and control
CENETIX	Center for Network Innovation and Experimentation
CDMSC	command dynamic model of situated cognition
CCG	China Coast Guard
CIEA	classification, identification, and engagement area
DMSC	dynamic model of situated cognition
DOD	Department of Defense
EAB	expeditionary advanced base
EABO	expeditionary advanced base operations
ECS	East China Sea
EEZ	exclusive economic zone
EMCON	emission control
EMSO	electromagnetic spectrum operations
FARP	forward arming and refueling point
HF	high frequency
INS	inertial navigation system
JADC2	Joint All-Domain Command and Control
LOA	littoral operations area
LOCE	Littoral Operations in a Contested Environment
MANET	mobile ad-hoc network
MCDP	Marine Corps Doctrinal Publication
ML	machine learning
NCW	network-centric warfare

NDM	naturalistic decision-making
NMESIS	Navy Marine expeditionary ship interdiction system
NOW	network-optional warfare
NSM	naval strike missile
OIE	operations in the information environment
OODA	observe-orient-decide-act
PAFMM	People's Armed Forces Maritime Militia
PLAN	People's Liberation Army Navy
RF	radio frequency
RPD	recognition-primed decision-making
SA	situational awareness
SATCOM	satellite communications
SCS	South China Sea
SHOR	stimulus-hypothesis-option-response
SUWC	Surface Warfare Commander
TMEABO	Tentative Manual for Expeditionary Advanced Base Operations
UAS	unmanned aerial system
UHF	ultra-high frequency
USMC	United States Marine Corps
VHF	very-high frequency
WEZ	weapons engagement zone

ACKNOWLEDGMENTS

First, I would like to thank my former boss, Major Ian Brown, for taking the time during our busy lives in the squadron to discuss Boyd and maneuver warfare. Your published works as well as your desire to continue the discourse on winning and losing inspired this research.

I would also like to thank my thesis advisors, Steve Iatrou and Dr. Mustafa Canan for your help and guidance throughout this research. I cannot overstate my gratitude for your willingness to meet on short notice to have dialogues about these concepts and granting me the latitude to explore the various topics in this research.

Most importantly, I want to thank my wife for her endless support throughout this process. Through both personal and professional challenges, you were there supporting me with patience and understanding every step of the way. I could not have done this without you.

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I. INTRODUCTION

Just as the nature of war encompasses those persistent aspects of war and the character of war describes those attributes that change over time, the same can be said of command and control (C2). The nature of command and control has remained relatively unchanged since ancient warfare, but the character of command and control evolved as armies grew larger, battlefields became more dispersed and technology permeated the battlefield. These attributes changed once again when the Marine Corps turned its attention to great power rivalries and competition against peer adversaries. As such it is important to examine how the current character of conflict impacts the character of command and control.

A. BACKGROUND

Since the ancient Greeks, new technology has altered the character of war and thus commanders have adapted their C2 systems to meet these needs. As armies and battlefields grew larger and more complex, commanders found new ways to execute command and control (Van Creveld, 1987). In this tradition, technological systems continue to have an increasing role in the C2 process. Executing the operational concepts of the *38th Commandant's Planning Guidance* requires advances in information systems technology in order to be able to execute concepts such as Expeditionary Advanced Base Operations (EABO) (Berger, 2019). While the Commandant of the Marine Corps asserted that C2 will remain a human intensive endeavor, maturing technologies such as artificial intelligence (AI), machine learning (ML) and cloud computing will likely have an impact on C2 (Berger, 2019). The mere presence of and access to data, does not necessarily mean that the commander has a better picture of the operational environment; in fact, it can create new challenges for the commander.

The warfighting theories of John Boyd have permeated Marine Corps Doctrinal Publications (MCDP) to include *Warfighting* and *Command and Control* (United States Marine Corps, 2018a, 2018b). However, because of the rapid growth of technology, Boyd's observe, orient, decide and act (OODA) loop may be insufficient, as it does not sufficiently take into account the growing impact of data and information systems on the decision-making process. This is because Boyd's focus is on the orientation phase of the cycle, and pays comparatively little attention to the observation phase. One can no longer take observations at face value. The observation phase is growing more complicated as the inputs to the system come from sensors and networked information systems. These systems by their nature have the ability to introduce error into the system, either intentionally or unintentionally, which can negatively impact the decision made by the commander.

B. RESEARCH QUESTIONS, METHODOLOGY, AND PATH

This research seeks to answer the following questions:

- How can the OODA loop be modified to reflect current technology and operating concepts?
- What is the impact of information systems on decision-making?
- How do decision making models that are relevant to military operations address the complexities of data and information flow?
- How can observational challenges impact decision-making in current operational concepts such as EABO and LOCE?

In the spirit of Boyd's *Destruction and Creation* this research analyzes C2 doctrine, the current operating environment, and applicable decision-making theories in order to synthesize them into a model that addresses the C2 challenges of the operating environment. Chapter II provides a review of decision-making literature in order to determine what concepts and models could be of use in order to transition the current concepts into one suitable for the environment. Chapter III examines Marine Corps C2 doctrine as well as prominent C2 literature including an analysis of Boyd's theories. Chapter IV describes the operating environment in terms of competition, EABO, and the C2 required for such operations. Chapter V develops the updated OODA loop. Chapter VI describes the vignette development and methodology. Chapter VII contains vignettes based on concepts of employment for EABO utilizing the updated OODA loop to determine command and control challenges.

C. PURPOSE OF RESEARCH

The purpose of this research is to explore how decision-making theories, models, and concepts that incorporate technical systems can augment Boyd's OODA loop in order to better illustrate the challenges of the current operating environment. This research seeks to update the OODA loop to reflect the current operational environment. In doing so, the updated model could provide planners with a more detailed mental model as they seek to implement concepts such as EABO. As current operational concepts call for sensors and shooters to be increasingly linked, while also being heavily distributed, it is important for decision makers to understand how data and information flow through these complex networks. This research will help commanders identify situations in which the data and/or information on which their decisions are based, may be flawed. By identifying potential sources of error, this study may help system designers account these sources and incorporate mitigation techniques into the design. More importantly, this research can help identify the decision-making impacts when data and information flows exist on a spectrum between deluge and trickle.

This research is not meant to be a contribution to cognitive psychology, or the body of work in decision-making theories. Instead, the goal of this research is to continue Boyd's discourse and advance the way tactical-level decision-makers think about thinking. It is intended to discover how the predominant decision-making theories and concepts from the past 30 years can be merged into Boyd's general theory of warfare in order to further that theory. The intent is to develop a model that can elucidate the impact of technological systems on decision-making in order to shape thinking about the current operating environment.

D. DEFINITIONS

Many of the terms throughout this research mean different things to different authors, and some may be used interchangeably throughout the literature and common parlance. In particular, terminology utilized in military publications often differs from the terms utilized in cognitive psychology even though they often point to the same concept. Given that this research targets military decision-makers, the research will, to the extent possible, adjust the terminology in order to align with military terms. As such, it is important to first define certain terms in relation to how they will be utilized in this research.

The information hierarchy (Figure 1) plays an important role in both Marine Corps and Naval doctrine by explaining how raw data leads to an individual's understanding, and helps define several terms. At the bottom of the hierarchy is data, which is comprised of raw, unformatted signals. Left unaltered, data has little utility, but once data is processed and put in an understandable form, it becomes formatted data or information (Department of the Navy, 1995; United States Marine Corps, 2018b). When one integrates pieces of information and provides that information with some context through the act of cognition, one gains knowledge or comprehension. The top of the information hierarchy is understanding, which involves giving greater situational meaning to knowledge through judgement and experience. With this understanding comes the ability to project or anticipate the future status of a given situation The end result of this process is for a decision-maker to gain situational awareness from which they can make a decision.

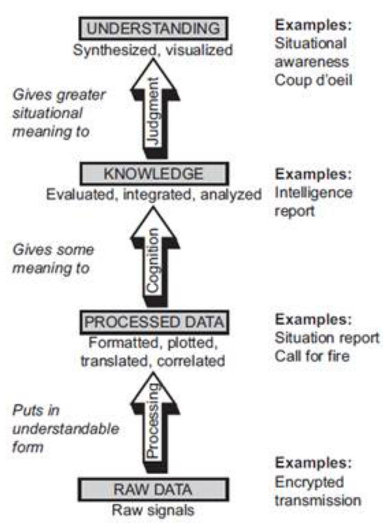

Figure 1. The information hierarchy. Source: United States Marine Corps (2018b).

This research utilizes the terms *commander* and *decision-maker* interchangeably, and the reader should view them as such. Due to the Marine Corps' doctrinal view of C2, one of centralized command and decentralized execution, there are certain decisions a commander makes, and certain decisions lower level leaders are authorized to make. As such, the models and theories described throughout the research apply equally to commanders and decision-makers. This is also a recognition that the enemy, especially a peer, has a vote in how events unfold. As such, in warfare it may not be the commander or even the designated leader that is forced to make a decision. Instead, it may be the individual on watch, at a given time, that is forced to make a tactical-level decision with strategic implications.

This research also uses the term *technological system* as a general term designed to encompass information systems (e.g. Palantir and databases), communication systems (e.g., e-mail, tactical chat systems, and radio communications), and weapons systems such as Aegis. This is an intentionally broad term in order to allow the reader to connect the systems with which they are familiar to the research. This allows the reader to apply the concepts discussed in the research to their C2 system.

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II. A REVIEW OF DECISION-MAKING THEORIES

Decision-making plays a critical role in C2 because it describes how a decision-maker determines what must be done. In order to modify the OODA loop to better reflect the operational environment, it is necessary to review the applicable decision-making literature in order to update the model. Given the vast array of literature, this chapter is limited to reviewing the literature most applicable to tactical-level military decision-making as it relates to the environment. This chapter reviews literature regarding sensemaking, situation awareness, naturalistic decision-making.

A. SENSEMAKING AND SITUATION AWARENESS

Weick (2008) defined sensemaking as the "ongoing retrospective of plausible images that rationalize what people are doing" (p. 1). In short, it is the constant process of observing what is occurring and attempting to make it clearer and justifiable (Weick, 2008). The process of sensemaking is perhaps the most important part of the decision-making process, because this examination of environmental cues determines the need to even make a decision (Weick, 2008).

Sensemaking and situation awareness (SA) are similar concepts and for the purposes of this research are considered synonymous. SA is knowing what is going on around oneself, yet it is much more than that because one's level of SA can impact one's decision-making and their performance (Endsley, 2000). A more complete definition of SA is that it is the combination of "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" in relationship to one's goals, objectives, or purpose (Endsley, 1995, p. 36). This definition emphasizes the importance of the temporal element, and yields three levels of situation awareness corresponding to perception, comprehension, and projection (Endsley, 2000).

As shown in Figure 2, a variety of elements impact one's SA. Technological systems effect SA through their capabilities, interface, user workload, complexity, and automation levels (Endsley, 1995). These elements have the capability to improve one's

SA by enabling a rapid, accurate, and clear perception of the applicable data to the user. However, if network connectivity is degraded, causing it to operate slowly, it can be difficult to obtain accurate information and can lead to increased uncertainty and incomplete perceptions. One's goals, objectives, preconceptions, and expectations impact SA by helping to drive what information is perceived and the context applied to it in order to comprehend and project those elements. This relates to the concepts of information-pull and information-push to be discussed in Chapter III. The technological system can facilitate SA by enabling a decision-maker to pull the pertinent information based on their objectives. At the same time, if organized in an information-push model, the decision-maker could be inundated with non-applicable data forcing them to devote more time and resources to perceive the desired data.

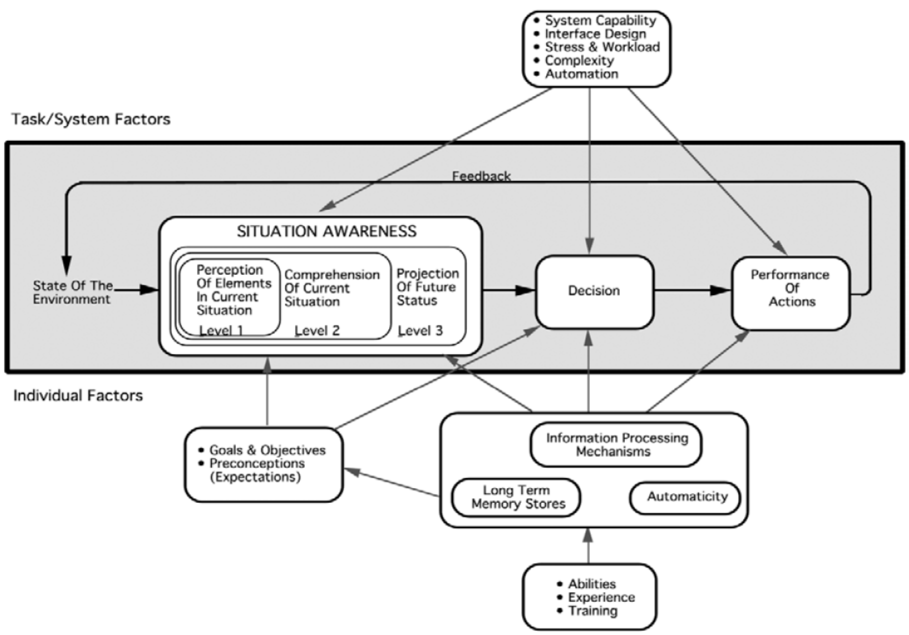

Figure 2. Model of situation awareness in relation to decision-making. Source: Endsley (1995).

As Endsley (2000) and Weick (2008) indicated, an individual can have a high-level of SA and still make a poor decision. Likewise, one can have a lower-level of SA, and make what turns out to be a good decision. Thus, while there is a link between SA and decision-making, the relationship is not coupled (Endsley, 2000). This is similar to Boyd's concept of orientation, so it could be said that one's SA drives the need to make a decision as well as what that decision may be.

Level 1 SA refers to one's perception of data elements and cues in the environment. One's perception of the environment is formed from all of the information sources available to an individual, whether it is through direct observation or through indirect observations as is the case with information systems (Endsley, 2000). As such, information systems can facilitate Level 1 SA by making more information available to the user; however, it can also hinder Level 1 SA by providing too much information such that the operator misses the pertinent information. An individual's goals impact perception because it can determine what data are sought (top-down processing) as well as act as a filter for what environmental data/cues are received (bottom-up processing) (Endsley, 2000). Recalling the Chapter I working definition of information as formatted data, Level 1 SA is impacted by the information-based problems of missing, unreliable, superfluous, or complex information which will discussed in Chapter III. For example, if a large amount of applicable information was unavailable due to emission control (EMCON) restrictions, it could limit one's ability to perceive the environment thus impacting Level 1 SA.

Level 2 SA refers to one's comprehension of the current situations based on the synthesis of Level 1 elements (Endsley, 1995, 2000). In other words, context is applied to the elements to derive meaning from them (Klein, 2000). One's comprehension of the situation is based on the synthesis of the Level 1 elements; however, that process is driven by the individual's mental model. One's goals impact the manner in which one provides meaning and context to data because those goals impact the mental model applied to the data.

Level 3 SA refers to the ability to project the future status of those perceived elements (Endsley, 1995). Once again, an individual's mental model drives what they perceive to be the future status. As one would expect, the accuracy of this projection is based not only on the validity of the mental model, but also how far in the future they attempt to project the future status based on the mission or task duration. This projection is what essentially drives the need to make a decision.

Mental models and active goals play a critical role in the development of SA as shown in Figure 3. One's active goal helps drive the selection of a mental model, and based on that mental model, the individual can direct their attention towards certain cues that allow them to perceive data relevant to their goals. The mental model also allows the individual to compare their perceptions to what they *should* see based on their mental model. The model also allows helps provide context to the data allowing an individual to comprehend its status and project its future status (Endsley, 2000). For example, one could have a mental model for what they should see from an adversary H-6J aircraft on a routine (non-threatening) flight, and a failure to see those cues could indicate that the flight is not routine.

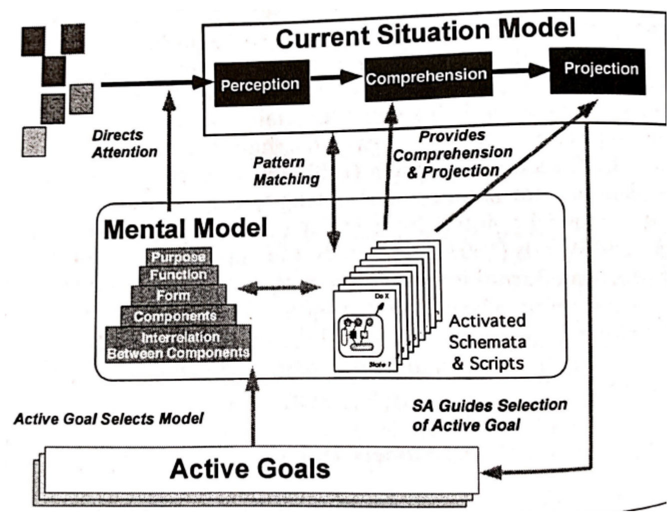

Figure 3. Impact of mental models on SA. Source: Endsley (2000).

As previously mentioned, the temporal aspect of situational awareness is critical in understanding how it impacts decision-making. SA must be understood within the context of how much time, be it perceived or actual, is available until some event occurs or some action must be taken that would impact their goals (Endsley, 2000).

B. DUAL-SYSTEM DECISION-MAKING AND HEURISTICS AND BIASES

In the dual-system model of decision-making there are two types of processes at work. System 1 (sometimes referred to as type 1) refers to fast and intuitive decision-making, and System 2 (sometimes referred to as type 2) refers to slower more reflective decisions (Evans & Stanovich, 2013). As Kahneman (2013) described, when one encounters a problem with which they are familiar or one in which they can distill into a simpler one, the mind typically utilizes System 1 thinking; however, when faced with an unfamiliar problem with no heuristic comparison the mind utilizes System 2 processes.

System 1 functions automatically with very little effort or sense of control on behalf of the decision-maker and in some respects may be thought of as autonomous (Evans & Stanovich, 2013; Kahneman, 2013). As such, these situations do not require the use of working memory and do not constitute a significant cognitive burden (Evans & Stanovich, 2013). A simple way to think about System 1 is that it is designed to arrive at a conclusion with little effort, utilizing very little evidence (Kahneman, 2013). System 1 is able to do this through the use of heuristics, which are mental shortcuts that reduce more complex problems or situations into simpler ones enabling System 1 to handle the decision-making process (Tversky & Kahneman, 1974).

System 2 operates largely in the background and monitors the operation of System 1, essentially endorses the operations of System 1 (Evans, 2008). In the event System 1 recognizes a situation that is too complex for it to handle, System 2 takes over providing a more in-depth, rules-based, conscious analysis process (Evans & Stanovich, 2013; Kahneman, 2013).

Challenging and complex situations require the in-depth analysis provided by System 2; however, in order for System 2 to activate it must recognize the difficulty of the problem (Kahneman, 2013). Evans (2008, p. 266) put it succinctly, "Heuristic judgments, which lead to biases, are associated with System 1, and analytic reasoning, which may intervene with these judgments and improve them, are linked to System 2." The challenge with this is that those heuristic judgments may mask the need for System 2 to operate, yet the time constraints of combat and agile systems may necessitate System 1 time scales. In other words, System 1 can cause a flawed sense of intuition and mischaracterize the problem or situation (Kahneman, 2013). Kahneman (2013) proposed the solution to this is to attempt to recognize situations requiring greater cognitive input and force oneself to think deeper about the issue. In short, one needs to catch themselves before jumping to a conclusion.

Not only can heuristics trick the mind into thinking issues are simpler than they are, the comparison they yield can be biased. These are not malicious biases or ones that are predicated towards a specific outcome or goal. Rather, they are an inherent part of heuristic comparisons (Kahneman, 2013). For example, the availability heuristic makes comparisons based off of the preponderance of examples in recent memory (Tversky & Kahneman, 1974). Returning to the previous example of the H-6J, if every day for the past month that same aircraft flew the same route without any hostile acts, one would be biased towards concluding that the current H-6J would follow the same pattern in the absence of further information.

Likewise, the representative heuristic seeks to classify something based on how representative of the classification it is (Tversky & Kahneman, 1974). Applied to this scenario, in the absence of definitive information, System 1 would seek to classify the aircraft as based on of the number of hostile characteristics exhibited. In this scenario, the aircrafts airspeed, altitude, direction, and emissions could indicate that it is hostile, so one may be biased towards concluding that it is hostile. This is particularly dangerous because while the aircraft could be exhibiting hostile attributes, its intent could be to harass U.S. forces.

The primary risk of heuristic-based decisions are the problems stemming from "intuitive judgments that arise from simplifying heuristics" (Kahneman & Klein, 2009, p. 519) The nature of the dual-systems and heuristics can lead to a false sense of understanding the situation (illusion of understanding), and a false sense of confidence in that understanding (illusion of validity). The sense-making ability of System 1 makes individuals "see the world as more tidy, simple, predictable, and coherent than it really is," which leads to the illusion of understanding (Kahneman, 2013, p. 204). Likewise, System 1 and System 2 construct a coherent narrative to describe the environment. Because the narrative is coherent and formed by the information at one's disposal and one's own beliefs, an illusion of validity can develop from this unjustified confidence in the judgement (Kahneman, 2013; Kahneman & Klein, 2009). Each of these illusions can contribute to a

SA or orientation that does not align with the true environment, which in turn can impact the final decision made and subsequent action taken. Technological systems can contribute to these illusions through a false sense of understanding the environment. Systems can provide more cues from which to make heuristic comparisons, but that does not necessarily mean those comparisons will be accurate.

Due to the vast amount of data made available by information systems, individuals often utilize heuristics to cope with information overload and uncertainty (Metzger et al., 2010). The same mental shortcuts and information-processing strategies can also be applied to determine what data are perceived and considered by an individual (Gugerty & Link, 2020; Metzger et al., 2010). One way to do this is to view only credible and relevant information based on the situation. While there are many heuristics that can be employed, some of the important ones for evaluating data credibility are: reputation of the source, endorsement of the source (also known as conferred credibility), consistency of the information with other sources, and whether the information differs from what was expected (Metzger et al., 2010). Relevancy can typically be controlled by search parameters and filters dictated by the individual's task (Shattuck & Miller, 2006).

While these heuristic approaches are necessary to filter through large amounts of information, it is important to note that heuristic biases are also present. For example, it is possible for a highly trusted and reputable source to provide inaccurate information. If the information is accepted and used to form an opinion based on the credibility of the source rather than an objective accuracy of the data, one invites the myriad problems associated with making such a flawed decision. Thus, once again, the risk of heuristic-based decisions stems from the simplification provided by that judgement (Kahneman & Klein, 2009).

As will be seen in Chapter III both systems are present, in the OODA loop. In Boyd's OODA loop (Figure 8) the *implicit guidance and control* arrow from orientation to action represents System 1 operations. In these cases the individual is able to quickly determine an action without further analysis. System 2 is embedded in the loop when an individual continues the orientation process, analyzes decisions and perhaps moves through multiple iterations prior to reaching a decision and action. From this, one could conclude that System 1 operations allow for a faster decision-making tempo and can help one operate inside an adversary's OODA loop. While this may be true in certain circumstances, it also means that such decisions are based on quick heuristic-based judgements, which may not be desirable against a thinking adversary.

The complicated environment described in Chapter V makes these types of judgements dangerous due to adversary deception, the nature of competition, and OIE (United States Marine Corps, 2020). The previously mentioned H-6J may simply be trying to impose costs on U.S. forces to devote the time, resources, and stress to determine the intentions of the aircraft and potentially bait the stand-in force to take an overly aggressive action against the aircraft. Such an action could be used to bolster Chinese support, domestically and internationally, for their actions while making the U.S. look like the aggressor. It is therefore critical that the stand-in forces recognize when they are making a heuristic-based judgement and attempt to analyze the situation to the extent possible given the time constraints (Kahneman, 2013). It is also important that the stand-in forces incorporate aspects of deception into their thinking to help trigger further analysis (Brown, 2016).

C. NATURALISTIC DECISION-MAKING

The study of naturalistic decision-making (NDM) focuses on how individuals make decisions in their actual environment as opposed to laboratory settings. Classical views of decision-making focused on decisions made in relatively well-defined and static environments where the focus could be on a single decision-point, such as a business merger (Orasanu & Connolly, 1993). Naturalistic decision-making focuses on settings that are much more applicable to military operations, including decisions made by experienced decision-makers making high-stakes decisions in environments containing: ill-structured problems, dynamic conditions, uncertainty, shifting/competing goals, and time constraints (Klein, 2017; Orasanu & Connolly, 1993). Thus, the operational environment as described in Chapter V is a naturalistic setting for those decision-makers executing EABO. Like the iterative nature of the OODA loop, decisions made in naturalistic settings are one decision in a string of actions that comprise an entire event, thus it is an iterative process containing various feedback loops (Orasanu & Connolly, 1993). Part of the goal of NDM was to demystify the concept of intuition by examining the cues utilized by experienced decision-makers to form their judgment and describe tacit knowledge (Kahneman & Klein, 2009).

NDM is concerned about the decisions made by experts within their realm of expertise as would be the case with a ship's captain, military commander, or stand-in force decision-maker. This is because decision-makers in these situations rely heavily on their experience in order to make decisions. According to Klein (2017), intuition allowed experienced decision-makers to match patterns in the data/cues they receive with their experiences in order to judge the typicality of the situation. In many respects, it is analogous to Boyd's use of *fingerspitzengefuhl*. This fingertip-feel allows commanders and other experienced decision-makers to quickly size-up a situation and determine whether it is one in which they are familiar or unfamiliar (Brown, 2018). Through pattern matching, an individual is able to test the alignment between expected and perceived cues, which allows them to adapt accordingly to anomalies. Additionally, Klein (2009, 2017) believed experienced individuals were more capable of conducting mental simulations in order to project the future status of the cues.

According to Klein (2009), one's ability to judge typicality is based on whether they have an appropriate mental model for the given situation, which is linked with experience. If the individual is familiar with the situation, they possess a mental model for that type of scenario and would be able to judge the relevant cues, expectancies, goals and potential actions based on that model. If the individual is not familiar with the situation, they attempt to construct a model based on what experiences they do have and by seeking more data (Klein, 2009).

Experience is important in NDM because many aspects of the process are driven by tacit knowledge. Klein (2009) described tacit knowledge as encompassing attributes such as perceptual skills, the ability to develop workarounds, pattern matching ability, the ability to judge typicality, and the variety and robustness of mental models (Klein, 2009). As one gains experience, they add to these knowledge capabilities, which is beneficial when making decisions. Novice decision-makers possess limited amounts of tacit knowledge. If put in a situation where they are making a decision, they have less tacit knowledge to draw upon in order to analyze the situation and make a decision (Klein, 2017).

As shown in Figure 4, formulating a decision takes both explicit and tacit knowledge; however, tacit knowledge is often more difficult to describe and harder to procure (Klein, 2009). One can see this relationship when learning to ride a bike, drive a car, or fly a helicopter. Through explicit knowledge, one can understand what they are *supposed* to do; however, actually doing it is another story. It takes time to build the tacit knowledge required to balance on a bicycle, make a safe left turn in a car, or to hover a helicopter. It takes experience in these fields to develop the ability to perceive the applicable cues, match them to something they know, judge what is going on, and make corrections.

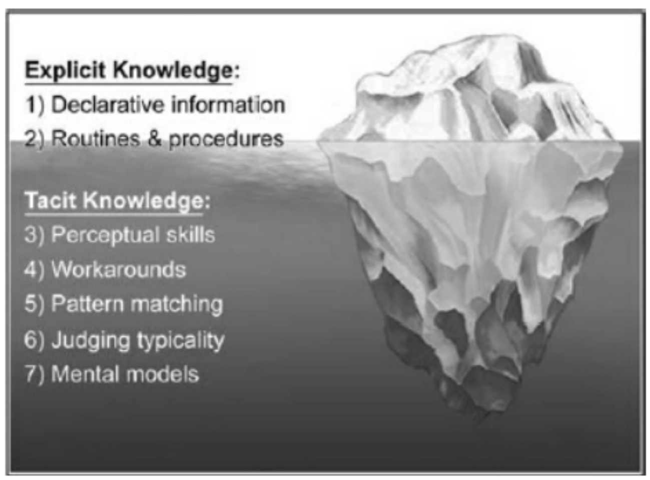

Figure 4. Explicit and tacit knowledge. Source: Klein (2009).

While there are a variety of different models of NDM based on the specific application, one of the most prominent is the recognition-primed decision (RPD) as seen in Figure 5. As the name indicates, this model is predicated on experienced individuals being able to recognize decisions that require some action. The model takes into account two important aspects of NDM: how the decision-maker observes and orients upon the situation and how they evaluate each option (Klein, 2017). This model focuses on how decision-makers assess the situation rather than the generation and comparison of decisions (Klein, 1993). Like the orientation phase of the OODA loop and SA, the focus is on the cognitive processes that facilitate a decision.

Figure 5 represents three variations of the RPD that could occur in a given situation. Variation 1 is the simplest variation, and explains what happens when a decision-maker faces a situation with which they are familiar. In this case the decision-maker experiences environmental cues and they are able to recognize the situation, match it with a resident mental model. The mental model of the situation helps determine relevant cues, cues they expect to see, their goals in the situation, and their course of action. Because it is a simple situation with which they are familiar, they are able to swiftly implement a course of action (Klein, 2017). In relation to the two-system (or dual process) model, this is analogous to System 1 functions. Variation 1 is similar to the previous example of the H-6J flying on a routine route. The cues from the environment indicate this is a typical event and the cue align with what is expected.

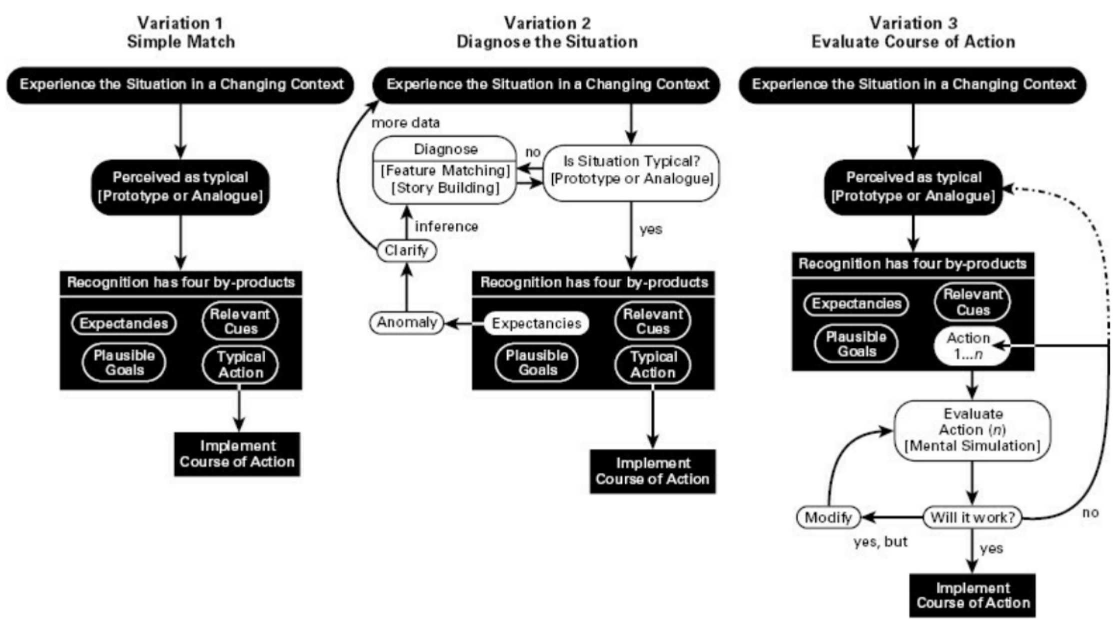

Figure 5. Recognition-primed decision model. Source: Klein (2017).

In Variation 2, the situation is more complex and the decision-maker may not be able to immediately diagnose the situation, so they need to analyze the situation in order to comprehend it. In this case, System 2 is activated and the decision-maker attempts to match the events in such a way that they are able to find a mental model, or merge multiple models, in order to accurately describe the situation. The decision-maker may also run through a mental simulation in order to help diagnose the situation. The decision-maker also uses mental simulation to generate expectancies that are used to constantly verify the validity of their diagnosis. If there is an anomaly, they try and clarify their diagnoses of the situation and gain more data in order to clarify the situation (Klein, 2017).

If instead of a single H-6J aircraft, Variation 2 could be illustrated by the cues indicating multiple H-6Js with fighter escorts. This would be an atypical event and the decision-maker would attempt to match various cues with other mental models to form a composite model and build a narrative of the event. Eventually they arrive at an understanding of the situation that while this is a larger formation, they still exhibit characteristics of a routine flight and no action would be required.

Variation 3 involves evaluating courses of action. Based on their experience, the decision-maker arrives at one or more potential actions. At this point, the decision-maker does not run through *every* option analytically or construct some sort of matrix to evaluate the options. Instead, they simulate the first option and determine if it will work. If the option works but requires modification, the changes are made and it is re-simulated. If the action will not work, they simulate the next option. If no options work, they will typically re-evaluate the problem. The key in NDM is that decision-makers are engaging in satisficing. They are not looking for the optimal or ideal solution, because the circumstances may not allow for such analytics. Instead, they are looking for the first solution that will work (Orasanu & Connolly, 1993).

In each of these variations, after the selected course of action is taken, the decision-maker observes the environment for cues to dictate follow-on actions (Orasanu & Connolly, 1993). This reflects the cyclical nature of NDM and reflects the feedback loops in the OODA loop as well as the concept of command and feedback.

Concepts of the dual-system approach and Boyd are present in NDM as depicted by the RPD. The black-filled portions of Figure 5 are largely System 1 functions and Boyd's implicit guidance and control leading to action. For example, in Variation 1 the decision-maker is able to rapidly move from cue to implementation rapidly with little effort and without the analysis to provide an immediate justification (Kahneman & Klein, 2009). On the other hand, in Variation 2 and Variation 3, the decision-maker's System 2 must interject in order to analyze the situation and action options respectively. This illustrates that the two systems are not mutually exclusive but can operate on a continuum as dictated by the situation (Evans & Stanovich, 2013). In terms of the OODA loop, the situation necessitates a more robust orientation and perhaps multiple iterations of a hypothesis.

Both NDM and the dual-system approach rely on the intuition of the decision-maker; however, they differ in what forms intuition. NDM posits that intuition stems from experience and tacit knowledge that one gains over time (Kahneman & Klein, 2009). An individual can apply this to various situations with which they are familiar. However, if one does not have the requisite experience to accurately recognize the problem, then that decision can be flawed (Klein, 1993). The dual-system approach posits that intuition stems from the ability to utilize simplifying heuristics to solve a problem thus allowing System 1 to resolve the problem (Kahneman & Klein, 2009). However, if this simplification is an incorrect characterization of the problem, once again the decision can be flawed. Thus, both theories can yield accurate and inaccurate decisions based on the individual, experience level, and their amount of tacit knowledge.

The concepts of NDM apply to EABO particularly because of the environment and the experience levels of the stand-in force. Given that the operational environment fits the definition of a naturalistic setting, the concepts of NDM provide another way to examine decision-making in this environment. One of the important take-aways is the importance of the decision-maker to extract cues from the environment. This is similar to Boyd's observation phase, and the perceptions of Level 1 SA. Applied to the operational environment, most of a decision-maker's cues will come from technological systems. Thus their ability to recognize a situation based on those cues is dependent on the attributes of the system to clearly and swiftly provide the necessary cues. If the system provides too many cues, the decision-maker may be inundated by information and unable to identify the salient cues. If the cues are insufficient or incorrect, it could cause the decision-maker's perception of reality to differ from the actual environment. Additionally, one of the challenges in this environment can be the decision-maker's desire to obtain continuously more information. In this case, the desire for more information is not to recognize the situation or determine an outcome, but rather to make them feel more comfortable with their decision or proposed course of action.

D. SUMMARY

This chapter examined a variety of sensemaking and decision-making models that are applicable to tactical decision-making in the given operational environment. Many concepts resident in these theories applied and reinforced concepts described by Boyd to include the importance of the orientation phase, the use of mental models, and the importance on the temporal aspect of decision-making. Central to these theories was some element of perception, comprehension, and projection that drove the need to make a decision as well as what decision could be made.

III. A REVIEW OF COMMAND AND CONTROL CONCEPTS AND DOCTRINE

What is command and control? As defined by the *DOD Dictionary of Military and Associated Terms*, command and control (C2) is "the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission" (Department of Defense, 2021). Hughes and Girrier (2018, p. 335) defined command and control as "the command organization, along with decisions made by and actions directed by the commander to employ force, counter-force, scouting, and anti-scouting resources to accomplish an objective." As one can imagine, the variations of this definition are quite varied to the extent that some authors, such as Vassiliou et al. (2014) devoted appendices to the varying definitions. In fact, command and control can mean almost anything to anyone; from simple radio communications to using the most advanced sensing and tracking systems (Coakley, 1992). Such varying definitions tend to mask the nature and character of C2.

This chapter examines the nature and character of C2 as viewed through the lens of the Marine Corps' doctrinal definition of C2, the challenges to C2, and prominent C2 models. In doing so, this chapter lays the foundation for the ensuing analyses of the operational environment and decision-making theories.

A. NATURE OF COMMAND AND CONTROL

Marine Corps Doctrinal Publication 6 (MCDP 6) defined command and control as the "means by which a commander recognizes what needs to be done and sees to it that appropriate actions are taken" (United States Marine Corps, 2018b, p. 1-4). As such, command and control is a process during which the commander seeks to make sense of a given situation, determine a course of action, and direct their assets accordingly, which aligns with the definition provided by Hughes and Girrier (2018). These definitions recognize what the Department of Defense (DOD) definition above does not: that C2 encompasses an element of decision-making and is thus an inherently human activity (Coakley, 1992). Herein lies the nature of command and control.

C2 can be further codified by separating it into its components. Command is simply the exercise of authority that must be exercised nearly continuously (United States Marine Corps, 2018b; Van Creveld, 1987). The Marine Corps executes this by utilizing a system of centralized command and decentralized execution. This enables the authority of the commander to be constantly applied through their commander's intent. This means that commanders tell their forces *what* needs done, and leave it to subordinate leaders to determine *how* to carry it out. This is known as mission-type orders. In this sense, the most important part of an order is the commanders intent: their vision for the operation. This provides the common ground and intent through which subordinates can execute their tasks. By its nature, this forces the commander to relinquish some control in the traditional sense; however, it allows subordinates to exercise initiative. The foundation for this is trust in subordinate leaders.

Builder et al. (1999) expanded this idea by describing command concepts as the commander's vision of a military operations. A command concept contained all the necessary information and direction that subordinates would need in order to execute the mission, and is more robust than the idea of commander's intent. Through this concept, Builder et al. (1999) postulated that communication during a military operation could be minimized and limited to modifying and/or verifying the command concept. Thus operations that required a tremendous amount of communications with the commander was indicative of a poor concept, and minimal communications demonstrated a robust command concept (Builder et al., 1999).

Traditionally, control is seen as a unidirectional, top-down process. In this model, the commander determines the actions to be taken and *controls* their forces in order to carry out the actions. Given the nature of warfare and the character of distributed operations, it is a fallacy to believe that a commander can control their forces precisely like chess pieces. As depicted in Figure 6, the Marine Corps views command as the same top-down function; however, it views control as a feedback mechanism that allows the commander to determine if their decisions have the desired effect (United States Marine Corps, 2018b). This is in line with Boyd's concept of command and monitor to be described later in this chapter.

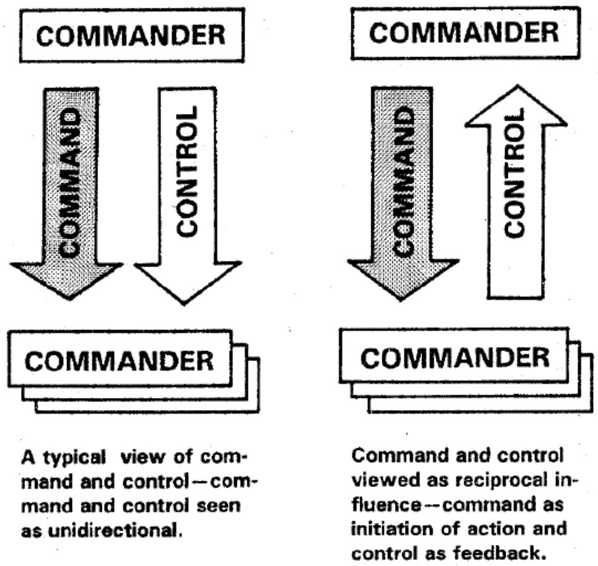

Figure 6. Two views of the relationship between command and control. Source: United States Marine Corps (2018b).

B. COMMAND AND CONTROL SYSTEMS

A C2 system is the combination of organizational considerations, personnel, information, technical means, and procedures that work together to *enable* the C2 process (Coakley, 1992; Department of Defense, 2021; United States Marine Corps, 2018b; Van Creveld, 1987). As described, technological systems represent only part of this complex system. Boyd's lectures (2018) and more recently Brose's analysis (2020) described an environment within the DOD where technology was seen as a panacea, and that applying technology and more exquisite systems would alleviate the problems of decision-making on the battlefield. In reality, the elements of the C2 systems are symbiotic. Changes or advances in one category without due considerations to the others can not only negate any benefits from the changes, but can stall the C2 process. Thus, advances in technological systems alone cannot solve the problems of C2, but rather those advances need to be combined with changes in organizational structures, procedures, and personnel in order to fully leverage the capabilities of the human-machine team.

C. COMMAND AND CONTROL CHALLENGES

Given that C2 is perhaps the most important single activity in warfare, disrupting C2 is a cost effective way to challenge adversaries (Hoehn et al., 2021). The two most important challenges to C2 are uncertainty and time. Decision-makers must contend with and balance the issues of uncertainty and time, because in many ways, command and control is, in part, an endless quest for the necessary level of certainty (Schmitt & Klein, 1996; United States Marine Corps, 2018b; Van Creveld, 1987). This quest is constrained by time (Fadok, 1995; Lawson, 1981; United States Marine Corps, 2018b; Van Creveld, 1987). As Schmitt and Klein (1996) described, uncertainty can stem from friendly, enemy, and environmental issues, which can be exacerbated by perceived or actual time constraints.

1. Uncertainty

Schmitt and Klein described uncertainty as "what [one] does not know or understand about a given situation" (1996, p. 63). While this is perhaps an oversimplified working definition, it is useful in the context of this research, and is important because uncertainty can prevent a decision-maker from making a decision and taking action at the required time. This fog-of-war can be the commander's (or decision-maker's) primary challenge in understanding the environment and determining what must be done (Paul et al., 2018).

This research utilizes uncertainty as an umbrella term to describe the issues of information uncertainty, complexity, ambiguity, and equivocality. These issues can be divided into information-based and knowledge-based issues as depicted in Figure 7 (Zack, 2007).[1] As described by Zack (2007), information uncertainty and complexity are information-based problems because they arise from issues regarding the data and information itself. Ambiguity and equivocality are knowledge-based issues because the issue is not with the data or information. Instead, an individual has difficulties achieving a sense of comprehension or understanding of the situation.

[1] Zack (2007) refers to these as problems of knowing.

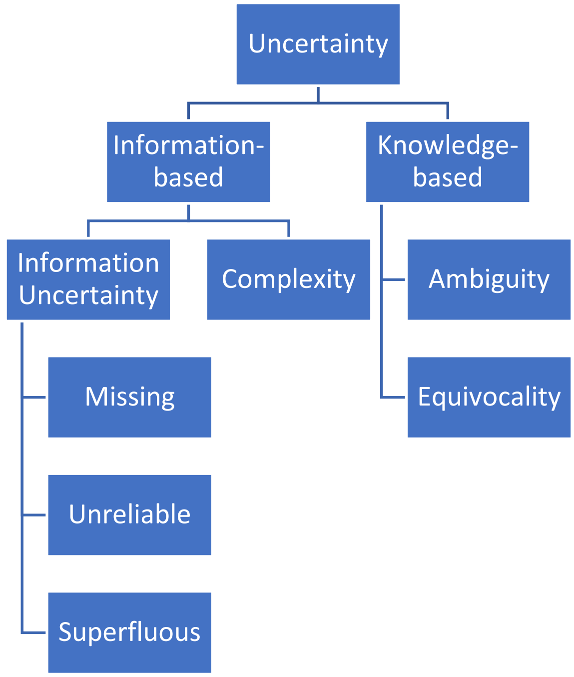

Figure 7. Elements of uncertainty. Adapted from Klein (1996) and Zack (2007).

Information uncertainty relates to the fog-of-war that stems from missing, unreliable, and superfluous information (Paul et al., 2018; Schmitt & Klein, 1996; Zack, 2007). Information is considered missing if it is not available when required by the decision-maker. This could occur if the required data was never collected, or if the data is unavailable due to problems accessing data (Schmitt & Klein, 1996). Information is unreliable when the source credibility of the data is low, or if the data may be outdated (Schmitt & Klein, 1996). As Buchler et al. (2016) and Marusich et al. (2016) concluded, this involves not only trusting the information, but whom within the C2 organization shares that information. Finally, it is possible to have too much information. In this case, there is simply too much information and an individual reaches the limits of their cognitive capacity resulting in an of information-fog. Information uncertainty problems make it difficult, if not impossible, to gain an understanding of a given situation, which in turn limits the soundness of any decision derived from that understanding (United States Marine Corps, 2018b).

As described by Zack (2007), complexity refers to a large number of parts that interact in a non-simple manner. Complexity issues arise when one has difficulty integrating disparate data from various sources in order to reach an understanding. Modern military operations are inherently complex, as they integrate multiple domains while being geographically dispersed (Van Creveld, 1987). This can take the form of poor interoperability between systems which force the human to piece together disparate information from various systems.

Ambiguity stems from the "inability to interpret or make sense of something" based on the available information, meaning that one may lack the experience or contextual background in order to effectively interpret the information (Zack, 2007, p. 1666). Thus, one can resolve ambiguity by reframing the information, gaining more contextual or explanatory knowledge, or by utilizing another's interpretation (Zack, 2007).

Equivocality is the opposite of ambiguity and exists when there are multiple interpretations of the same thing (Zack, 2007). In this instance, individual unambiguous interpretations may conflict with each other, and can potentially be caused by conflicting data. Once again, the solution to the equivocality problem is to confer with others in order to remedy the varying interpretations, and arrive at a common understanding.

Based on a study of Marine Corps regimental C2, Schmitt and Klein (1996) found that nearly 50 percent of all cases of uncertainty stem from knowledge-based problems. As such, this is not a problem that can be resolved by gaining more information, but rather an issue requiring additional context or additional interpretations. In other words, ambiguity can be mitigated to an extent by those with sufficient experience or by collaborating with others (Katz, 2019).

There are two methods to cope with uncertainty: attempt to decrease uncertainty, or embrace uncertainty (Canan & Soykan, 2016; United States Marine Corps, 2018b). Conceptually, resolving uncertainty is a combination of both accepting some level of uncertainty while trying to decrease it to a manageable level. Thus, increasing the amount of available information does not necessarily lead to reduced information uncertainty (Buchler et al., 2016; Marusich et al., 2016).

2. Time

Each of the previously mentioned challenges has a temporal aspect with which decision-makers must contend. For example, in a short period of time, a decision-maker may not be able to gather more data and information in order to cope with information uncertainty. Likewise, that time constraint can limit their ability to piece together the disparate information resulting from complexity. Time can also prevent decision-makers from consulting with others in order to remedy issues of ambiguity and equivocality.

Time is perhaps the greatest constraint in resolving uncertainty. In combat situations, the amount of time available is often outside of the decision-maker's control. There are many situations where the adversary dictates how much time one has in order to make a decision, as would be the case when contending with an inbound aircraft. Fleeting opportunities can also limit the amount of time a decision-maker has to contend with these issues, as the opportunity may no longer exist after a given amount of time. Finally, friendly operations can act as a time constraint as well. If there is a mission on a timeline, a decision-maker only has a certain amount of time in order to make a decision or risk throwing of the timeline of the entire mission, which can have rippling effects should the mission involve several different air assets.

D. JOHN BOYD AND THE OODA LOOP

Boyd's general theory of war was instrumental in the development of maneuver warfare and Marine Corps warfighting doctrine (Brown, 2018). As such, Marine Corps C2 doctrine is also heavily influenced by Boyd's *Organic Design for Command and Control*. This section describes Boyd's theories as they apply to C2, and examine their shortfalls based on how C2 functions today.

Boyd believed that, "we must be able to form mental concepts of observed reality, as we perceive it, and be able to change these concepts as reality itself appears to change" in order to make timely decisions (Boyd, 1976, p. 2). This means that individuals must be able to form and modify mental models in order to cope with complexities and uncertainties in order to understand the environment (Boyd, 1976). These mental models guide one's perception of how the world works and therefore influence how one thinks and operates

(Senge, 2006). In other words, mental models help provide context to one's perceptions. This aligns with the concepts of mental models discussed in Chapter II

In order to explore this idea, Boyd utilized a scientific trinity that drove the preponderance of his thoughts: Kurt Gödel's Incompleteness Theorems, Werner Heisenberg's Uncertainty Principle, and the Second Law of Thermodynamics (Boyd, 1976). From Gödel, Boyd found that in order to validate a concept, there existed a constant cycle between making observations to sharpen the concept, and then using that concept to refine subsequent observations (Boyd, 1976). If such inward-oriented validation continued, it would only expose more uncertainties and create more entropy in accordance with Heisenberg and the Second Law of Thermodynamics respectively (Boyd, 1976). An increase in information caused entropy levels to increase, which made it necessary to break down the current mental model in order to create a new mental model, such is the essence of destruction and creation and the OODA loop. Putting it more concisely, Fadok stated, "one cannot determine the nature and character of a system within itself and, furthermore, any attempts to do so will lead to greater disorder and confusion" (1995, p. 14).

Boyd's OODA loop is the manifestation of this synthesis. At a basic level, the OODA loop, as depicted in Figure 8, illustrates the ability to observe reality, formulate a perception of that reality, and use that perception to make decisions and act on those decisions. As the cycle continues, new observations enter the loop, which enable one to break down previous perceptions of reality and create a new perception.

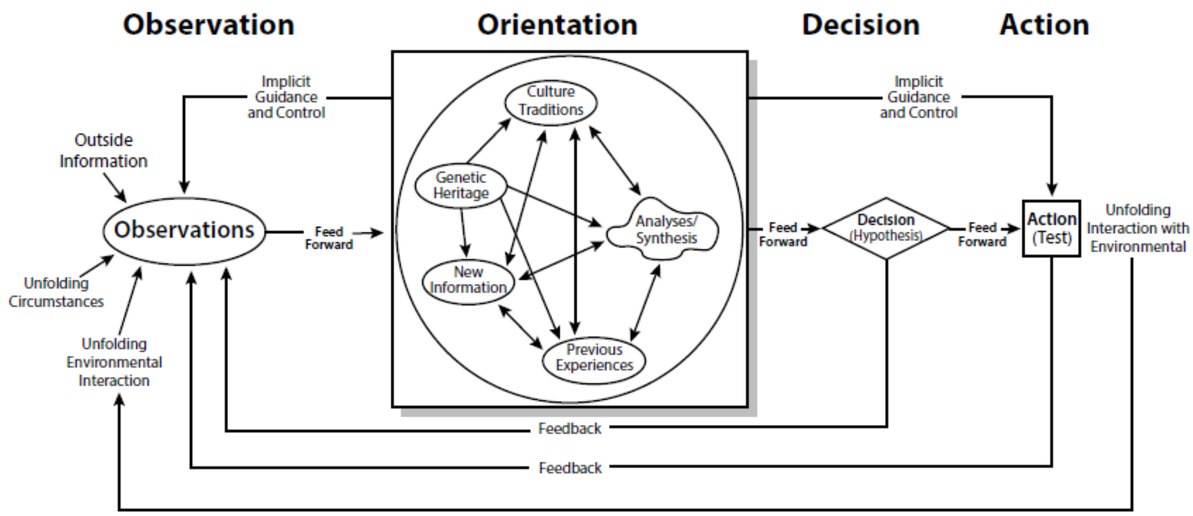

Figure 8. Boyd's OODA loop. Source: Boyd (2018).

This process of destruction and creation occurs in the OODA loop through the cognitive processes in the orientation phase. As described in Boyd's *Organic Design for Command and Control*, "Orientation is an interactive process of many sided implicit cross-referencing projections, empathies, correlations, and rejections that is shaped by and shapes the interplay of genetic heritage, cultural tradition, previous experiences, and unfolding circumstances" (Osinga, 2007, p. 193). These traits within the orientation process act as a set of filters shaping one's understanding of the environment and ultimately drive future observations, decisions, and actions (Boyd, 2018). Through this process, individuals make sense of observations by analyzing them based on those attributes and synthesizing them into a perception of reality. It is important to note that in Figure 8, the analyses/synthesis aspect of orientation is in an amorphous shape which reinforces the idea that what emerges from orientation is a perception of reality and potentially fallible. In order for this orientation to be successful, those mental images need to match the actual environment (Hammond, 2012).

Boyd observed that the processes of observation, orientation, decision, and action represent the same series of events that occur during the command and control process, so the OODA loop is representative of command and control (Boyd, 2018). This is an important connection because viewing the OODA loop as a C2 loop enables one to link Boyd’s concepts related to the OODA loop to C2.

Perhaps the most important linkage is that operating within an adversary’s OODA loop is synonymous with operating inside the adversary’s C2 loop (Boyd, 2018). As such, the concepts of relative tempo apply to C2, in that a decision-maker who can observe, orient, decide, and act faster than their adversary has the advantage. Because of this, Boyd emphasized the importance of the orientation phase as it was the key portion of the loop that allowed the commander to make sense of the observations and drove their decisions, actions, and future observations.

While orientation is widely be considered the most important part of the OODA loop, it must be acknowledged that one cannot orient properly without the requisite information derived from observations (Boyd, 2018; Hammond, 2012). The only way into an OODA loop is through observations, so if something is not observed, it cannot feed into one’s orientation (Boyd, 2018). As shown in Figure 8, these observations come from a variety of interactions with the external environment. In order for these sources of information to be able to be analyzed and synthesized, they must first be sensed. Thus, it could be said that if it cannot be sensed, it does not enter the loop (Boyd, 2018).

Boyd’s theories focused on the human element of conflict. Boyd stated that “terrain does not fight wars. Machines don’t fight wars. People do it and they use their minds…machines are just tools that you use” (Brown, 2018, p. 202). This is not to say that he was an opponent of technology in general. After all, he was a fighter pilot and was instrumental in developing what would become the F-16 (Brown, 2018; Hammond, 2012). What Boyd (2018) detested was the view at the time that technology was a panacea and that the solution for any problem was to add more sensors, increase communications, and improve displays; unfortunately, this idea still permeates the DOD (Brose, 2020).

Decision-makers increasingly make decisions based on observations derived from technological systems (indirect sensing) as opposed to directly observing the environment (direct sensing) (Hughes & Girrier, 2018). This means that before unfolding interactions with the environment and unfolding circumstances can be considered observations, they must be sensed, formatted, transmitted, and displayed before it can be considered an observation entering one's OODA loop. Examining these delays are important because of Boyd's emphasis on the temporal element. Often the OODA loop is viewed from a systemic level in that the entire loops needs to be executed at a faster rate relative to the adversary. However, Plehn (2000) recognized that examining it at a component level exposes the processes that *enable* the loop to be executed faster.

Both Brehmer (2005) and Plehn (2000) described delays within the OODA loop; however, their delays require refinement. The first is *sensor delay*, which is the interval from an event occurring to sensors detecting the event. As it pertains to this operational environment, this could be the delay between an adversary launching a missile and a sensor detecting the launch. Sensor delay can be effected by a variety of items such as sensor coverage, the type/band of energy to be detected by the sensor, as well as sensor specific techniques such as staring and scanning sensors (Olsen, 2016; Plehn, 2000). Additionally, there is *processing delay*, which is the interval between when the system detects the event and when that data is formatted and displayed/presented as useable information (Phillips et al., 2007). Such delays could stem from communications latency and processing capacity.

One must also account for the *implementation time*, which is the time between when a decision is made and the initiation of the associated action, and *action time*, which is the time from when an event is commenced and when it takes effect (Brehmer, 2005).[2] These are important concepts for command and control as they impact the decision-maker's ability to have the desired impact.

Understanding that most observations come from technological systems that have delays associated with them is important for command and control because it has implications on the ability of the decision-maker to make a timely decision. This means that technological systems can contribute to delays as can the human cognitive processes. This also indicates that observations, like orientation, are part of a process. As such, it is

[2] Brehmer (2005) refers to these terms as *dead time* and *time constant*; however, these terms tend to be misleading as to the nature of the delay.

important to expand the notion of observations beyond that of Boyd's OODA loop in order to better reflect the impact of technological systems. This relates to the previous discussion of uncertainty and time.

E. OTHER COMMAND AND CONTROL MODELS

This section examines several C2 models that appear repeatedly throughout the literature. Such models can potentially augment Boyd's OODA loop because the underlying theories of the models (e.g., cybernetics, cognitive science and organization theory) can provide some useful insights (Builder et al., 1999). As such, each model has benefits and drawbacks based on the underlying field of study. This is not to say that these theories are *wrong,* but rather illustrates the strengths and weaknesses of the models. This section will explore two of the more prominent C2 models, explain their benefits, drawbacks, and their contribution to C2.

1. Lawson Model

The Lawson model is a cybernetic approach to modeling a command and control system as a process (Builder et al., 1999). Lawson believed the system, depicted in Figure 9 must have the ability to: perceive (sense) the environment, compare that perception to the desired state, and, if necessary, take action to bring the perceived environment closer to the desired state (Lawson, 1981). Lawson (1981) stressed the importance of the system to be able to provide the commander with an accurate representation of the environment. If it cannot provide the current picture of the operational environment, then it is of limited use to the commander.

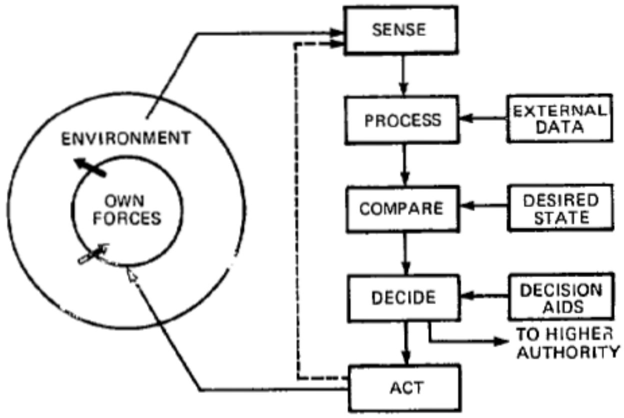

Figure 9. Lawson model of C2. Source: Lawson (1981).

As depicted in Figure 9, the Lawson model takes into account the need for technological systems to sense and process the data prior to the decision-maker being able to compare it with its desired state. Also useful is the incorporation of external data (i.e., data not sensed from the environment) into the act of processing. While not depicted on the model, Lawson's (1981) work addressed the issue of time, and the impact it has on C2. While Figure 10 is a relatively simple analysis, it has tremendous implications for a C2 systems, which can be better realized when put in the context of responding to the launch of an anti-ship cruise missile (ASCM). If the event is the launching of the ASCM, then the response time that one must be concerned about is when the friendly missile intercepts the adversary missile. Thus, the system must detect the event, alert personnel, reach the decision to fire, and then actually fire the missile in such a time to allow that missile to intercept the incoming ASCM.

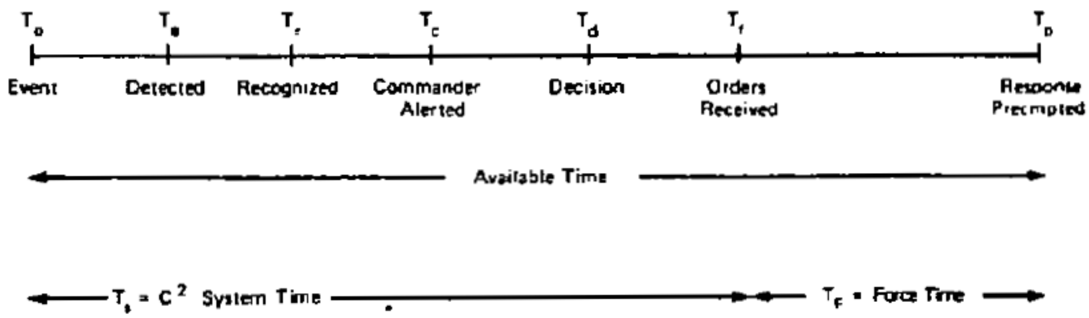

Figure 10. Lawson's timeline analysis. Source: Lawson (1981).

After initial publication, Lawson incorporated an adversary loop into the model, as depicted in Figure 11, which is also quite useful in the study of C2. First, that friendly and enemy forces share the same environment that can be sensed by both sides. Second, just as friendly forces can sense portions of the enemy force, so too can the enemy force. Third, that the enemy is going through these same general processes in order to execute their own command and control. Finally, because the adversary is going through the same process, they are a thinking adversary trying to take action on friendly forces in order to achieve their desired state (Hughes & Girrier, 2018).

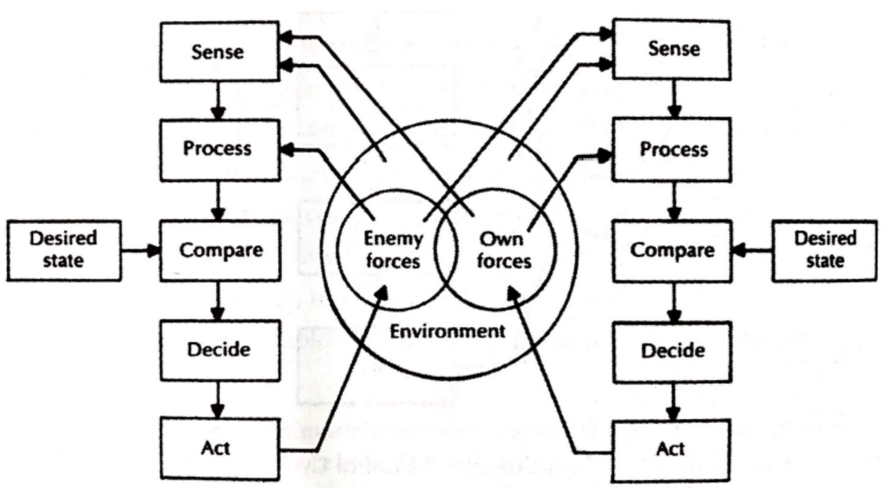

Figure 11. Lawson model with enemy. Source: Hughes and Girrier (2018).

While many cybernetic models such as Lawson's accurately depict the steps and processes of command and control, they inadequately represent the complexity that humans bring to the system (Builder et al., 1999). Where Boyd's model expanded on the orientation phase, the Lawson model does not expand on this element. That being said, Lawson's timeline analysis as well as incorporating the enemy aspect provide more insight into C2 challenges.

2. Wohl Model

Wohl's stimulus, hypothesis, option, response (SHOR) model (Figure 12) integrated aspects of the cybernetic paradigm with cognitive science by blending the process steps with the transformation of the data throughout the process (Builder et al., 1999). By considering the human element, Wohl (1981) addressed the ability of the decision-maker to undergo a stimulus-response process where they quickly determine an option and/or response based on their familiarity situation and information available. This is similar to the concepts discussed by Klein (2017) and Kahneman (2013) from Chapter II. While it is not readily apparent from the model, Wohl (1981) embedded the cognitive and sensemaking aspects within the stimulus, hypothesis, and option stages to indicate that it is a continuous process.

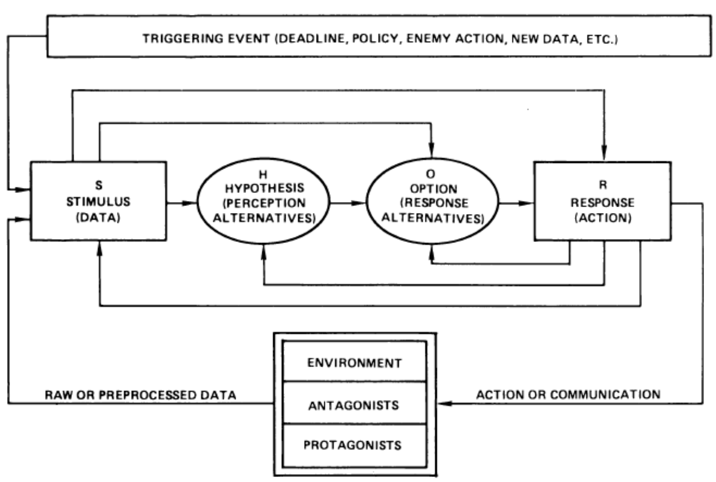

Figure 12. Wohl's SHOR model. Source: Wohl (1981).

F. THE DYNAMIC MODEL OF SITUATION COGNITION

The dynamic model of situated cognition (DMSC) integrated the human aspects of decision making with the characteristics of technological systems to produce a model that accurately describes what occurs in complex environments (Shattuck & Miller, 2006). In the DMSC, a series of ovals and lenses represents how data is extracted from the environment, formatted into information, and how the human element then makes sense of that information in order to produce a comprehension and projection of the environment. The left side of Figure 13 represents the inputs of technological systems and shows how data transitions from the external environment to being available to the decision-maker. The right side is the human portion of the system and incorporates the perceptual and cognitive aspects of sensemaking that allows users to perceive, comprehend and then project information. In doing so, it describes the formulation of each level of SA. In terms of Boyd's OODA loop, observations align with Oval 4 and orientation aligns with the processes through Ovals 5–6. As such, the DMSC shows that technological systems introduce a process to observations that are not necessarily captured by Boyd's OODA loop.

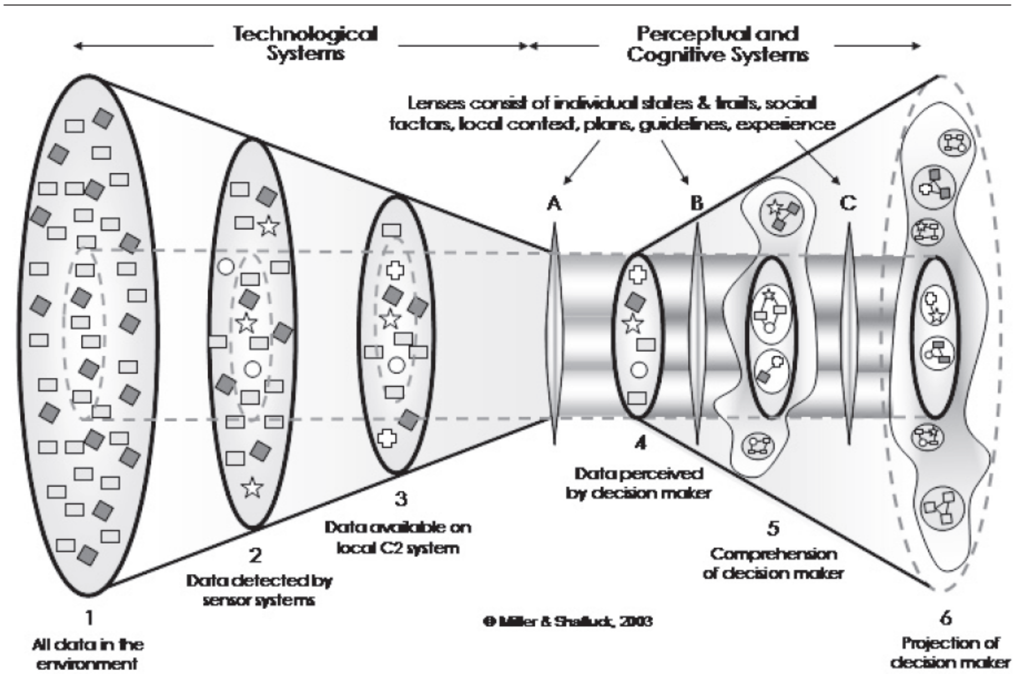

Figure 13. Shattuck and Miller's dynamic model of situated cognition. Source: Shattuck & Miller (2006).

In Figure 13, Oval 1 is the ground truth reality and completely accurate. As such, the model is dynamic because Oval 1 is constantly changing and evolving with the environment (Shattuck & Miller, 2006). Everything, whether it can be sensed or not, is present in Oval 1. Oval 2 represents data that are detected by systems, which is, at best, a subset of the data available in Oval 1, because sensors cannot capture *everything* in the environment. Of the data that are sensed, Oval 3 represents the subset of what data is actually available to a decision-maker (Shattuck & Miller, 2006).

Data inaccuracies are inherent in systems and occur due to a variety of reasons. Unsensed data are not present after Oval 1. This can occur due to out-of-band data, inadequate sensor coverage, or malfunctioning sensors. Data that was misidentified either due to adversary spoofing or algorithm errors appear as stars and circles in Oval 2 (Shattuck & Miller, 2006). Data that are filtered out by the system are no longer depicted in the system, and data that are displayed incorrectly are represented by a cross in Oval 3 (Shattuck &

Miller, 2006). These errors are important because they propagate through the system and can impact a decision-maker's comprehension and projection of the environment.

The perceptual and cognitive portion of the model contains three lenses each of which act as filters to affect how information is perceived, comprehended, and projected (Shattuck & Miller, 2006). At least six classes of information comprise the lenses: individual states/traits, social factors, local context, the plan/mission/orders, guidelines/ doctrine, and past experiences (Shattuck & Miller, 2006). As one could imagine, these attributes are just as dynamic as the environment and are continually influenced by new information and experiences as well as physiological and psychological states. While each of the lenses encompasses the same attributes, they each perform different functions (Shattuck et al., 2007). Lens A affects what information is actually *perceived* by the decision-maker in Oval 4, so what is perceived is a subset of what is available in Oval 3 (Shattuck & Miller, 2006). Lens B influences how the user organizes the perceived data into information to formulate a comprehension of the environment in Oval 5. Likewise, Lens C affects how that comprehension becomes their projection about the future in Oval 6 (Shattuck & Miller, 2006).

In Ovals 5 and 6, the composed figures within the dark ovals represent the comprehension and projection of the decision-maker respectively. Thus, in a similar manner to Boyd, the end result is an orientation on the situation. Amorphous shapes Surround these ovals and represent alternate ways to synthesize the information into comprehension and projection (Shattuck & Miller, 2006). These take into account the idea that there can be differing orientations on the same data (Hammond, 2012; Shattuck & Miller, 2006).

The desired end state is for a decision-maker to achieve a level of SA in Oval 6 such that it represents Oval 1 to the extent necessary to make a prudent decision. This is represented in the left graph in Figure 14. As depicted, there is a decreasing percentage of data available as one progresses through the system. It is possible that an experienced decision-maker, through their knowledge, attributes, and attitudes in their lenses, is able to form a more accurate comprehension of the environment from the limited perceived data in Oval 4 (Shattuck et al., 2007). In other words, an experienced decision-maker can fill in missing pieces in order to form a more complete picture. Thus, by Oval 6 the projection of the environment closely resembles Oval 1. The graph to the right in Figure 14 demonstrates the impact of erroneous data permeating through the system, and demonstrates how the decision-maker's comprehension and projection can marginally reflect reality. One must also take into account the decision-maker's lenses: a *well-focused* lens can help mitigate the erroneous data whereas a *poorly-focused* lens can promote the distortions (Shattuck et al., 2007).

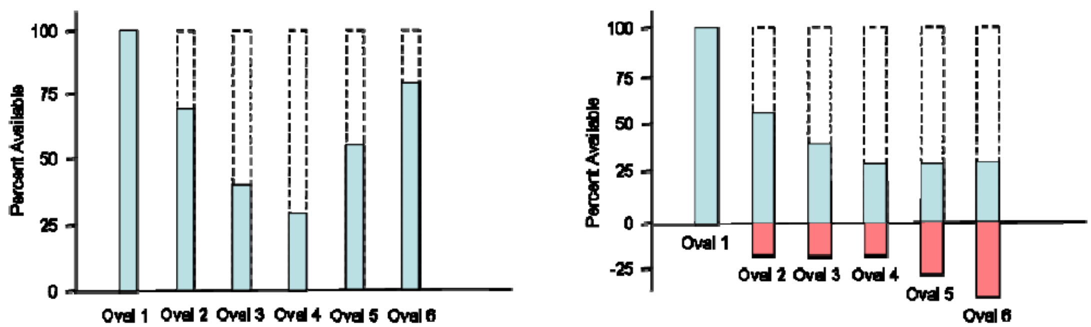

Figure 14. A quantitative view of the DMSC. Source: Shattuck et al. (2007).

Like the OODA loop, the DMSC contains feedback loops to represent the cyclical nature of the model. Because one's comprehensions and projections impact future iterations of the model, feedback loops emanate from Ovals 5 and 6 to each of the preceding ovals as depicted in Figure 15. As a decision-maker orients on the situation, they may add data to the environment (Oval 1), adjust sensor coverage (Oval 2), adjust collection or display requirements (Oval 3), and even adjust their information-pull (Oval 4). Likewise, one's projection of the environment (Oval 6) influences future iterations of their comprehension of data (Oval 5). As previously mentioned, decision-makers' lenses are just as dynamic as the environment. Thus, there are feedback loops that extend from both Oval 5 and Oval 6 to each of the lenses as depicted in Figure 16 (Shattuck & Miller, 2006). Thus as Shattuck and Miller stated, "The comprehensions, projections, and decisions we make contribute to *the manner in which we view the world*" (Shattuck & Miller, 2006, p. 11)

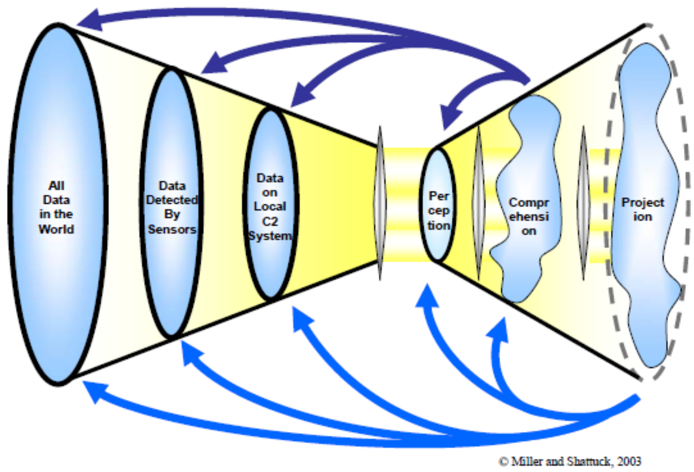

Figure 15. Feedback loops from Ovals 5 and 6 to Ovals 1–4. Source: Miller and Shattuck (2006).

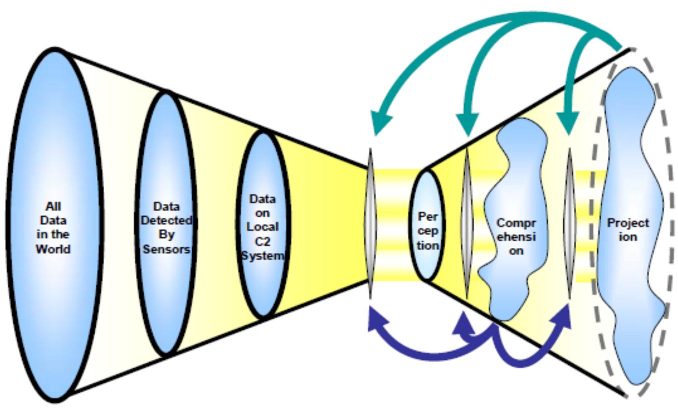

Figure 16. Feedback loops from Ovals 5 and 6 to the lenses. Source: Miller & Shattuck (2006).

One of the primary benefits of the DMSC is the ability to link technological systems with human cognition thereby linking multiple portions of a C2 system. This facilitates some important insights as to how those systems can impact decision-making especially in the operational environment. The size of Oval 2 is directly related to the ability to sense the environment. As sensors increase in quantity, have a greater range, provide higher quality data, and are able to capture more of the environment, Oval 2 increases in size. Such improvements can help scout more of the environment in order to counter the ranges of adversary sensors and systems (Hughes & Girrier, 2018). Conversely, adversary OIE, particularly electro-magnetic spectrum operations (EMSO) can diminish the size of Oval 2 by preventing sensors from obtaining data. Thus, Oval 2 is also dynamic.

Philips et al. (2007) added to the study of the DMSC by incorporating a processing block between Ovals 2 and 3. The addition stemmed from their analysis on the time required from when data was sensed (Oval 2) to when it was perceived by the user (Oval 4). Their dataset demonstrated that organically sensed data could move relatively quickly from Oval 2 to Oval 4 meaning that the user was able to perceive it in a timely manner (Phillips et al., 2007). However, when the data was part of a *data dump* from higher headquarters, it took hours for that information to become available (Phillips et al., 2007). This has important implications for the operational environment. Due to the limited connectivity, large influxes of data could happen more frequently once connectivity is restored, and take time to process. Thus, potentially important information may not be available to a decision-maker due delays in processing the data and enabling the user to perceive the information.

One can also gain greater insights by expanding the meaning of Oval 2 to encompass networked information systems especially in light of the extensive networking described by Joint All-Domain Command and Control (JADC2) which will be discussed in Chapter IV. Data stored in the cloud-like environment would be considered part of Oval 1. As data is stored and shared, one's ability to access that data would be encompassed by Oval 2. This is the same concept as being connected to cloud storage on one's personal computer. The data resides in the environment, and in order to access it one needs network connectivity. This is an important extension for the operating environment. If connectivity is unrestricted, one would have a large Oval 2 because they have access to a larger amount of data from the environment. However, when RF communications are contested and EMCON procedures imposed ones access to this data would significantly decrease thus shrinking Oval 2. In order to leverage the increased data, the system must be able to process and display that amount of information (Oval 3). Perhaps the most limiting factor, is the user's ability to perceive that data (Oval 4) (Buchler et al., 2016; Marusich et al., 2016).

Both Boyd (2018) and Lawson (Hughes & Girrier, 2018) described friendly and adversary C2 systems interacting with each other, and the G. A. Miller et al. (2007) expanded the DMSC to do the same thing. Because the battlespace is shared by both friendly (blue) and adversary (red) forces, both entities share Oval 1. As such, friendly and adversary DMSCs can be depicted as shown in Figure 17. This depiction helps re-frame how one conceptualizes the battlespace and supports the notion of getting inside an adversary's decision-making process while protecting one's own against deception and OIE (Brown, 2016).

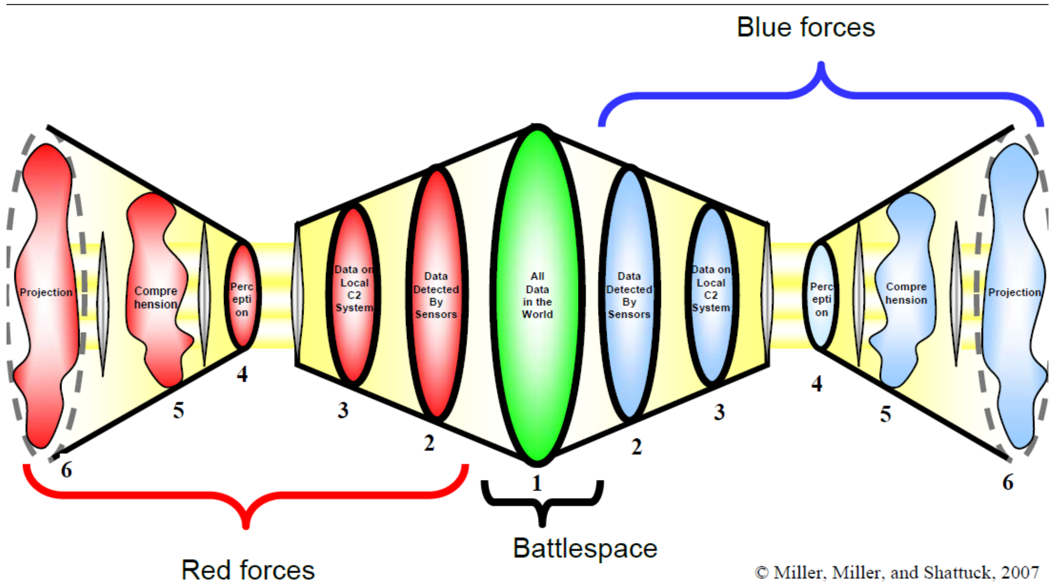

Figure 17. Red and blue forces in the DMSC. Source: Miller et al. (2007).

Both friendly and adversary forces share the environment, but what sets them apart and allows each side to capture their desired data is their Oval 2 capabilities. Because red and blue forces possess their own suites of sensors with their own capabilities and limitations, each side has their unique Oval 2. From there, their own systems and processes can facilitate red and blue situational awareness. This also shows that through means such as cyber operations and signals intelligence that one can access the other's data by developing the appropriate Oval 2 capabilities.

Figure 17 is particularly useful when examining the operational environment. Both U.S. and Chinese forces are competing within the same information environment. The access of each side to the data in that environment relies on their sensor coverage and their ability to present that data. Each side's lenses provide a means through which to perceive the data, reach a level of comprehension, and project likely future events.

The DMSC shows that while there may be ample data in the environment, the ability of that data to impact a decision-maker's orientation is based on the ability to correctly sense and display the data while also enabling the decision-maker to perceive the pertinent information. Extending this same thought to EABO, the ability of the stand-in forces to correctly orient on the situation is predicated on their ability to accurately execute the DMSC. They must correctly sense and synthesize the data so their projection in Oval 6 aligns with the environment in Oval 1.

G. COMMAND DYNAMIC MODEL OF SITUATED COGNITION

Katz (2019) applied the DMSC to studies of military hierarchies and structures to create the command dynamic model of situated cognition (CDMSC), which demonstrated how information gaps inherently form as information flowed from sensor to decision-maker. Like in command and feedback, the direction from the commander flows from the top-down; however, as Figure 18 shows, the data and information flow from the bottom-up. The model consists of three levels. At the bottom of the hierarchy are technical specialists who are support staff such as system operators, clerks, analysts, etc. The second level consists of the principal advisors who could be thought of as department heads or staff, and the third level is the commander (Katz, 2019). The benefit of these terms is that they can be applied to nearly any hierarchy.

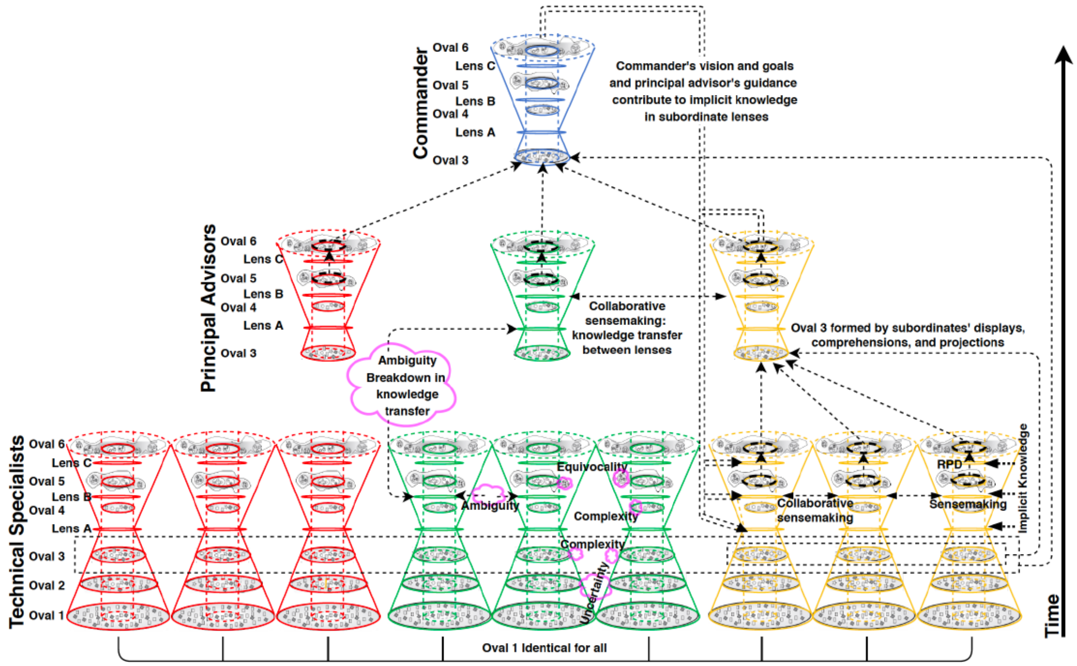

Figure 18. Command dynamic model of situated cognition Source: Katz (2019).

Perhaps the most important aspect of the CDMSC is how it illustrates the variations of the DMSC as one moves up the hierarchy. The system operators, the technical specialists are the individuals actually working with those systems in question. Oval 1 is the same for each of the specialists as discussed in the previous section. Depending on the type of system and location of the system, one can begin to see differences in their Oval 2. For example, the red column may have a different Oval 2 than the green column because they are in completely different locations. Within like-color columns, Oval 2 can be different between individuals because of the different types of sensors and spectrums in which they operate. From there, each individual continues through their DMSC to formulate a projection (Katz, 2019). As depicted in Figure 18, groups can engage with others both laterally and vertically in order to resolve some uncertainty.

Because technical specialists work for the principal advisors, they essentially fulfill the role of the sensors in the principal advisor's DMSC (Katz, 2019). Principal advisors receive their inputs come from the projections of the technical specialists. Additionally, because principal advisors can view the screens of the technical specialists, they have access to their Oval 3 (Katz, 2019). This enables them to not only utilize their projections, but also view the information available to them as they formulated that projection. This same process occurs at the commander's level. The projections of each of the principal advisors form the inputs to the commander's DMSC, and the commander has access to the information present on each of the technical specialists' Oval 3s throughout the command (Katz, 2019).

Katz' (2019) analysis of information gaps demonstrated that data and information errors generated at the technical specialist level can permeate through the hierarchy to influence the projection of the commander, and thus their decisions as well.

The expansion of Oval 2 discussed in the previous section also applies to the CDMSC. For example, data sensed by a sensor (Oval 2) in the red column could be stored as either sensor data or formatted information in Oval 1 via a cloud-like environment. This would enable technical specialists from the green and yellow columns to access this data as long as they have the connectivity and bandwidth to retrieve the data. When communications are uncontested, this would mean that each of the columns would have a greatly expanded Oval 2. However, if the information environment became contested, individual Oval 2s could shrink based on the type of denials and degradation. In practical terms this could prevent entities from retrieving data from the environment as well as sharing data in the environment.

H. SUMMARY

This chapter discussed the concepts of Boyd's OODA loop and views of command and control as they related to Marine Corps C2 doctrine. As such, the Marine Corps views command and control simply as the means by which the commander recognizes what must be done and sees that the appropriate actions are taken (United States Marine Corps, 2018b). This means that the OODA loop and decision-making theories are central to the execution of C2.

Given this model, Boyd's *Organic Design for Command and Control* showed that C2 in many ways are layers of OODA loops. In order to defeat an adversary, one's OODA loop needs to turn at a faster tempo than an adversary's. When this is applied to a C2 construct, the overall system of OODA loops must operate at a faster tempo. Marine Corps doctrine facilitates this speed by a command and feedback mentality where the commander makes a decision, communicates it to their forces and seeks feedback to drive further decisions. This also facilitates mission command where commanders communicate their intent to subordinates and allow them to operate in such a manner that it fulfills that intent.

Because of the Marine Corps' view of command and control and its use of mission type orders, it is critical that lower-level decision-makers are able to make the appropriate level decisions in accordance with the commander's intent. Linking this to Boyd's OODA loop, this means that the decision-maker must be able to observe the environment and orient on it in such a manner that their understanding with the environment allows for a decision that is in-line with the commander's intent. Additionally, as the environment changes, the decision-maker must have a means to update their commander's intent should the greater situation change.

While the "elegant simplicity" enables its application to myriad domains, it also leads to shortfalls (Gray, 1999, p. 91). Most notably is that the observe phase of the loop does not take into account the impact of technological systems. Models such as the Wohl and Lawson models identify the presence of technological systems, but do not describe the impacts on decision-making. The DMSC offered a way to update the OODA loop by incorporating elements of technological systems.

IV. CURRENT OPERATING ENVIRONMENT AND CHALLENGES

As the character of conflict changes, so too must the character of command and control. While the nature of command and control largely remains unchanged, the character of it must change to enable the commander to exercise command and control as the character of warfare changes. Vassiliou et al. (2014) proposed that four megatrends (Figure 19) impact the future of C2 and drive changes in C2 systems: big problems, robustly networked environments, ubiquitous data, and new forms of organization. In this context, strategic competition with China is the big problem. The re-born concepts of Network-centric Warfare (NCW) as Joint All-Domain Command and Control (JADC2) form the robustly networked environment. The increased amount of data provided by the network as well as the distribution of forces contributes to the ubiquitous data. Finally, the organizational aspect of distributed maritime operations (DMO) and EABO drive new forms of organizations and the challenges contained therein. This chapter explores each of these as they relate to C2 doctrine and theory. In order to limit the scope of this chapter, the analysis will be limited to China; however, it should be noted that these concepts would apply to other peer adversaries as well.

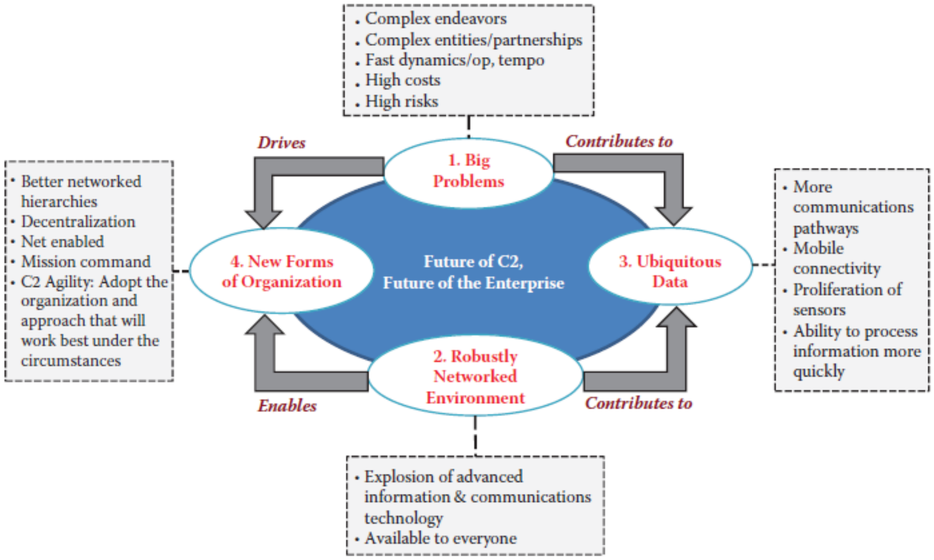

Figure 19. Megatrends transforming C2. Source: Vassilou et al. (2014).

A. COMPETITION

The idea of competition stems from adversaries such as Russia and China conducting a variety of malign activities to slowly and incrementally achieve their own national objectives while remaining below the threshold of violence (Department of the Navy, 2020). In order to combat this, U.S. and allied partners must uphold the rules-based order in order to thwart incremental gains (Department of the Navy, 2020). This is akin to the U.S. involvement in the Tanker Wars during the Iran-Iraq War where then Secretary of Defense Caspar Weinberger said, “We are not at war, but certainly not at peace” (Levinson & Edwards, 1997, p. 4). Figure 20 illustrates this environment as a competition continuum where forces can be involved in operations below the threshold of violence, yet any missteps during those operations could cross that threshold.

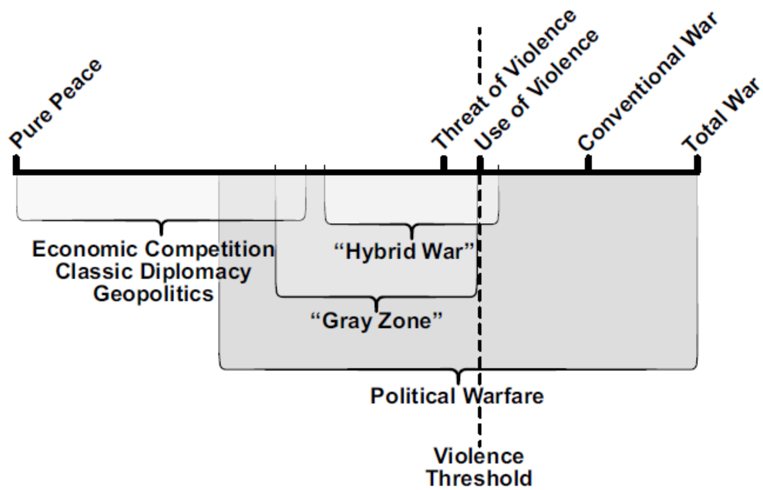

Figure 20. The linear competition continuum model. Source: United States Marine Corps (2020).

Chinese territorial disputes regarding the Paracel Islands, Spratly Islands, Scarborough Shoal and the Senkaku Islands create tensions between China and countries like Japan, the Philippines, Taiwan and Vietnam, and effects the balance of power in the region (O'Rourke, 2021b). Additionally, Chinese expansion into the Spratlys and other islands in the South China Sea (SCS) and East China Sea (ECS), to include the construction of man-made islands, enables China to project power past the First Island Chain (Department of Defense, 2020). Chinese maritime forces accomplish their aims through coercion and intimidation, and the goal of U.S. and allied forces is to counter this through their presence (Department of the Navy, 2020; O'Rourke, 2021b).

Executing C2 in such an environment is inherently difficult; in fact, it is more difficult than executing C2 conventional war(Hughes & Girrier, 2018). In this environment, the tactical situation and associated decision-making can and will have significant strategic implications (Tangredi, 2018). This strains the ability to execute mission command because of the risks associated with crossing the threshold of violence by mistakenly firing on a Chinese aircraft or PLAN vessel. Crossing that threshold, or even approaching it, could have ramifications ranging from nuclear threat to restricting the export of rare earth metals (Fleischaker & Sinnott, 2021; Tangredi, 2018).

B. A2/AD OPERATING ENVIRONMENT

Anti-access/area denial (A2AD) capabilities seek to provide a credible threat against vessels in a given area. This prevents adversary vessels from operating in a certain area without accepting an unreasonably high level of risk (United States Marine Corps, 2021). China's A2AD capabilities are driven by a combination of long range anti-ship cruise missiles, anti-ship ballistic missiles, long range over-the-horizon radar systems, increasingly capable naval forces, and an array of man-made islands from which to deploy those forces (Department of Defense, 2020; O'Rourke, 2021b; United States Marine Corps, 2021).

Figure 21 depicts some of China's A2AD capabilities in the SCS, and shows that U.S. and Allied vessels operating in these areas do so within the weapons engagement zones (WEZ) of a variety of adversary weapons systems including advanced anti-ship cruise missiles (ASCM) and anti-ship ballistic missiles (ASBM) (Department of Defense, 2020). To counter such a threat, the Marine Corps developed the EABO concept to allow the Marine Corps to operate within the WEZ and provide a consistent presence. Traditionally the Marine Corps fights from the sea onto shore, but in this case, the concept is reversed to project sea power from ashore. By utilizing a light, highly mobile, highly capable, and dispersed force, the Marine Corps seeks to "reverse the cost imposition that determined adversaries seek to impose on the joint force" (Berger, 2019, p. 11). In doing so, the concept shifts the discussion from how the U.S. will operate in the vicinity of Chinese forces, to how China will be able to operate in the presence of U.S. A2AD systems (Lacey, 2019).

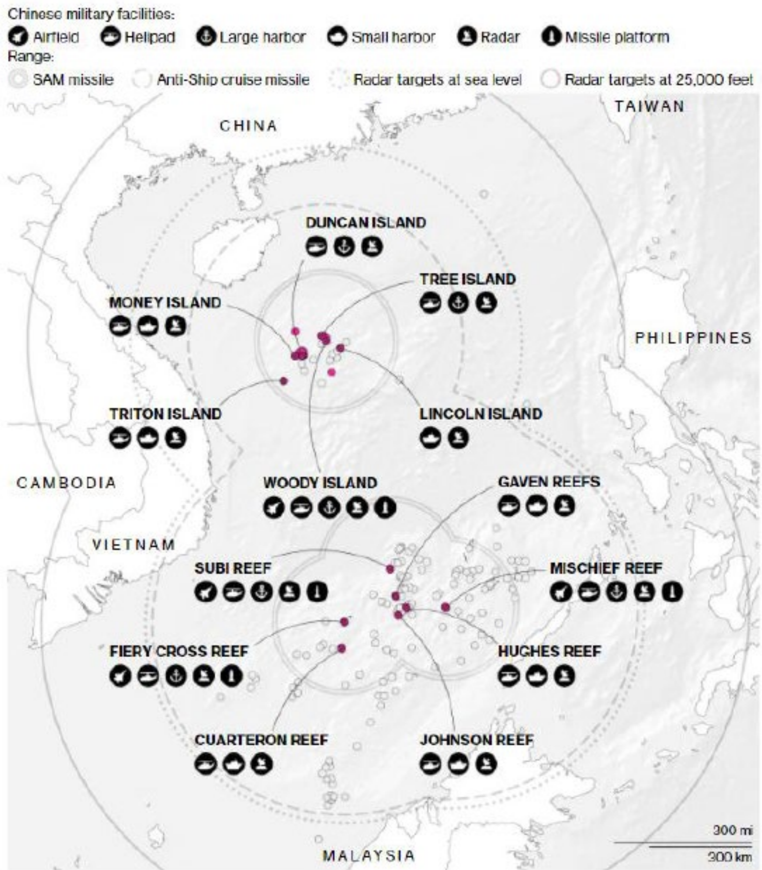

Figure 21. Chinese military facilities in the South China Sea. Source: O’Rourke (2021b).

The persistent threat of operating within the WEZ creates C2 challenges in an A2AD environment. Operators must always be on the alert and prepared for if/when the adversary intends to cross the threshold (Berger, 2021). Through the use of the OODA loop, decision-makers must be able to observe adversary actions, determine whether they present a threat, if that threat necessitates crossing the threshold of violence, and determining the prudent course of action. These observations are generally the product of technological systems, so those forces must be equipped with the systems and processing capability to organically determine the status of an adversary threat system.

There is also a human element to this as well. The stresses of being on alert when combined with the uncertainty and ambiguity the adversary injects into the scenario can have tremendous impacts on one’s decision-making capability (Hughes & Girrier, 2018;

Klein, 2017; United States Marine Corps, 2020). These human factors can impact the manner in which one orients upon a situation.

C. EXPEDITIONARY ADVANCED BASE OPERATIONS

EABO are defined as a "form of expeditionary warfare that involves the employment of mobile, low-signature, persistent, and relatively easy to maintain and sustain naval expeditionary forces from a series of austere, temporary locations ashore or inshore within a contested or potentially contested maritime area in order to conduct area denial, support sea control, or enable fleet sustainment" (United States Marine Corps, 2021, p. 1-3). These operations involve the use of stand-in forces and stand-off forces that are designed to operate inside and outside of the WEZ respectively. Some of their potential tasks include surveillance and reconnaissance, surface warfare operations, air and missile defense, strike operations, and forward arming and refueling point (FARP) operations (United States Marine Corps, 2021).

Figure 22 depicts a representation of stand-off and stand-in forces. If one pictures each iteration of the stand-in force as an OODA loop, the decision-maker at each of the iterations must be able to execute that loop in order to continuously observe the environment, orient on the situation, decide on a course of action and take the necessary action.

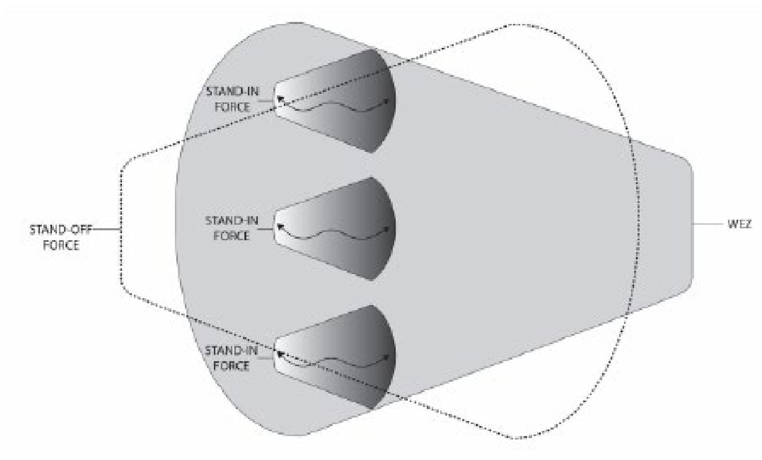

Figure 22. Depiction of stand-off and stand-in forces. Source: United States Marine Corps (2021).

Ideally, in an uncontested information environment each of the stand-in forces would be able to collect and share their sensor data to allow each of the stand-in forces and the stand-off force to achieve a similar orientation. This would allow each force to incorporate a greater number of observations into their orientation and gain a better orientation of the littoral operations area. When commanders and their subordinates share the same orientation, the subordinates are better situated to execute the commander's intent in the form of mission orders (Boyd, 2018). Thus, in this scenario, a commander could reasonably be assured that their lower-level decision-makers are equipped to execute their intent without further direction. However, this capacity diminishes as the information environment becomes contested and/or forces become more widely dispersed.

While littoral forces are reliant on higher echelons for information and intelligence, they may not have access to these observations in an EMCON or contested information environment (United States Marine Corps, 2021). When this occurs, uncertainty can increase significantly, presenting a block to the C2 process. A unit's observations may be limited to their organic sensing and processing capability meaning that the inputs into their OODA loops decrease and can diminish their ability to orient correctly resulting in a flawed perception of the operating environment (Hammond, 2012). This could be mitigated by overlapping sensor coverage to the extent possible, which may allow those forces to capture the same data; however, depending on the dispersion of the forces, this may not be possible. When this occurs, it would be more likely that the various stand-in forces develop varying orientations of the environment, which in turn drives decisions and actions.

Likewise, as data and information sharing decreases, it diminishes the ability of higher echelons to monitor and evaluate the progress of these operations thus increasing uncertainty at higher levels. This means a commander has fewer inputs into their OODA loop, which may limit their ability to orient and correctly assess the situation, which in turn affects their decision-making capability.

The danger in these varying orientations is that different elements within the littoral operations area could have different perceptions of the environment. Given the right combination of perceptions, personality, and authority, it is certainly conceivable that these align to result in unintended engagements or missed opportunities.

The purpose of EABO is to be able to operate within the adversary WEZ, so, naturally, time represents a challenge to C2. With longer range sensors and engagement ranges, the time available to execute the OODA loop diminishes (Hughes & Girrier, 2018). As such, sensor delays, processing delays and others can have tremendous impacts. Likewise, once that information is available to the decision-maker, if it is not readily consumable or displayed in such a way to yield a clear interpretation, it can extend the orientation time required. All of these aspects can stretch the OODA loop, and all of them are the result of technological systems.

D. NETWORK CENTRIC WARFARE AND JOINT ALL-DOMAIN COMMAND AND CONTROL

Joint All-Domain Command and Control (JADC2) is the DOD’s vision for the future of C2 systems, yet it has its roots in the concepts of Network Centric Warfare (NCW). Because JADC2 will form the basis for the technological systems utilized during EABO it is important to examine how NCW and JADC2 can impact C2.

As described by Cebrowski and Garstka (1998) NCW is the idea that advanced information sharing would enable greater awareness across the battlespace and enhance the ability to deter or prevail in a conflict. A DOD report to Congress described how NCW was embodied by four tenets:

1. A robustly networked force improves information sharing.
2. Information sharing enhances the quality of information and shared situational awareness.
3. Shared situational awareness enables collaboration and self-synchronization; and enhances sustainability and speed of command.
4. These, in turn, dramatically increase mission effectiveness (Department of Defense, 2001, p. 4-1).

These tenets act as linked hypotheses that build upon each other to create a value-added chain that could improve C2 (Alberts, 2017).

Hughes and Girrier (2018) described perhaps the most important aspect of NCW in that the range and speed of modern missiles significantly increase the area that must be scouted in order to gain a sufficient amount of data. This coverage could best be achieved by integrating sensors from various platforms and sharing it so that the overall mosaic covers the desired area. In this context, NCW is not a concept declaring that networks are the panacea, but rather a necessity in order to maintain the scouting and decision-making capability required by modern weapons. In other words, it can expand Oval 2 of the DMSC.

It is important to remember that NCW was a concept to drive the implementation, integration, and usage of sensors and networks. It consists of sensor, C2, and shooter grids that overlap. Thus through robust networking and data-sharing, one is literally linking together sensors, decision-makers and shooters (Hughes & Girrier, 2018). By linking together these three entities, decision-makers could have access to a tremendous amount of data, which it was believed would lead to better decisions. However, having too much information can lead to information overload and uncertainty, so simply having more data does not automatically lead to better decision-making. Despite this, having access to a plethora of data is in-line with the concept of a commander's information-pull. Such a connected network allows the staff to seek specific data desired by the commander. Additionally, if the data had not already been collected, such connectivity could allow the collection of said data in a shorter period of time, since they would have access to a wider array of sensors distributed across the environment (United States Marine Corps, 2018b).

As the NCW literature indicates, such changes in technology also require organizational changes in order to prevent information from becoming bogged down in hierarchical systems. Likewise, higher velocity information requires procedural changes to ensure the commander receives the most current information (Alberts et al., 1999). This reinforces the concept that changes in the technological aspect of the C2 system necessitates adjustments in other portions of the system in order to take full advantage of the changes.

The Naval services intend to leverage Project Overmatch and JADC2 as part of the networking structure to operate in this environment (Department of the Navy, 2020). JADC2 is the DOD's concept to connect sensors from each of the military services into a single network in order to "enable faster decisionmaking" (Hoehn, 2021, p. 2). In fact, "JADC2 intends to help commanders make better decisions by collecting data from numerous sensors, processing the data using artificial intelligence algorithms to identify targets, and then recommending the optimal weapon…to engage the target" (Hoehn, 2021, p. 2).

Despite this vision of data sharing across the Joint Force, it still must contend with the denied and degraded information environment as previously discussed. The network promises to be resilient with all things being connected, and, by leveraging AI, the AI could determine which paths are available and efficient (Berger, 2019; Galdorisi, 2021; Hoehn, 2021). Yet, unless communication methods are developed utilizing other-than radio frequencies (RF), they are still subject to EMCON and being contested. Thus, forces conducting operations in these regions must still be able to operate in a data and communication limited environment.

E. NETWORK OPTIONAL WARFARE

One of the main drawbacks of NCW and JADC2, especially in the littorals against a peer adversary, is that they require constant network connections. Network traffic flows transmitted through RF enable adversaries to detect the presence of friendly units. Additionally, adversary operations in the information environment (OIE) could impact the friendly forces ability to communicate, even in a network such as JADC2.

One of the ways to combat this is to utilize network optional warfare (NOW) (Hughes & Girrier, 2018). The idea behind NOW is that network connectivity is able to be adjusted based on the threat level and EMCON. When there are no restrictions, the network could operate as normal, but, when necessary, communications could be kept at an absolute minimum. Such a concept not only requires the development of alternative forms of communication, but more importantly, it requires units to be able to function without the ability of communications.

F. SUMMARY

This chapter described the current/future operating environment and described the challenges it poses to C2 and C2 systems. The technological problem stems from a contested information environment, so forces need to be able to form an accurate orientation of the environment under full and restricted communication and data availability. This creates challenges at the personnel level because as inputs to the OODA loop are limited, one has a limited ability to sufficiently orient on the environment. Organizationally, the differences in the observe-orient process can cause decision-makers at different levels to arrive at different decisions and actions. Additionally, the impacts of limited information sharing and communication can increase levels of uncertainty, which exacerbate an already time constrained environment.

JADC2 as a concept is in development in order to provide the benefits of NCW to the operating environment. However, while such a robust and resilient network could link sensors, decision-makers, and shooters, it still must contend with the limitations of RF communication.

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V. MODEL DEVELOPMENT

A. OODA LOOP 2.0: A MODEL FOR COMPETITION AND EABO

This model is intended to be an update of Boyd's OODA loop that incorporates pertinent concepts from decision-making theories (Chapter II) in order to enable C2 concepts (Chapter III) to be utilized in the current operating environment (Chapter IV). OODA loop 2.0 (Figure 23) incorporates the various theories discussed during this research while maintaining the overall OODA construct. This allows for the continued application of *A Discourse on Winning and Losing* at a systemic level while reframing how one views the loop at a component level.

B. INTERNAL VALIDATION

Because the DMSC was developed to account for the impact of technological systems on decision-making, in this model it is embedded in the observe and orient portions of the OODA loop. The technological systems portion resides under the observe and the perceptual and cognitive systems reside under orientation. In doing so, it more accurately describes how these processes are conduct or will be conducted in the operating environment.

1. Observation

An individual's observations are not predominantly directly sensed from the environment, but rather an in-direct observation provided by a system (Hughes & Girrier, 2018). This is not to say that *all* observations come from systems, which is why there are inputs between Oval 3 and Lens A, that stem directly from the environment. In this way, these direct observations fall in the same spot on the DMSC as those from other advisors. In a larger sense, one's observations are a combination of what one observes via technological systems and what one directly observes from the environment, which may, or may not, compete with one another.

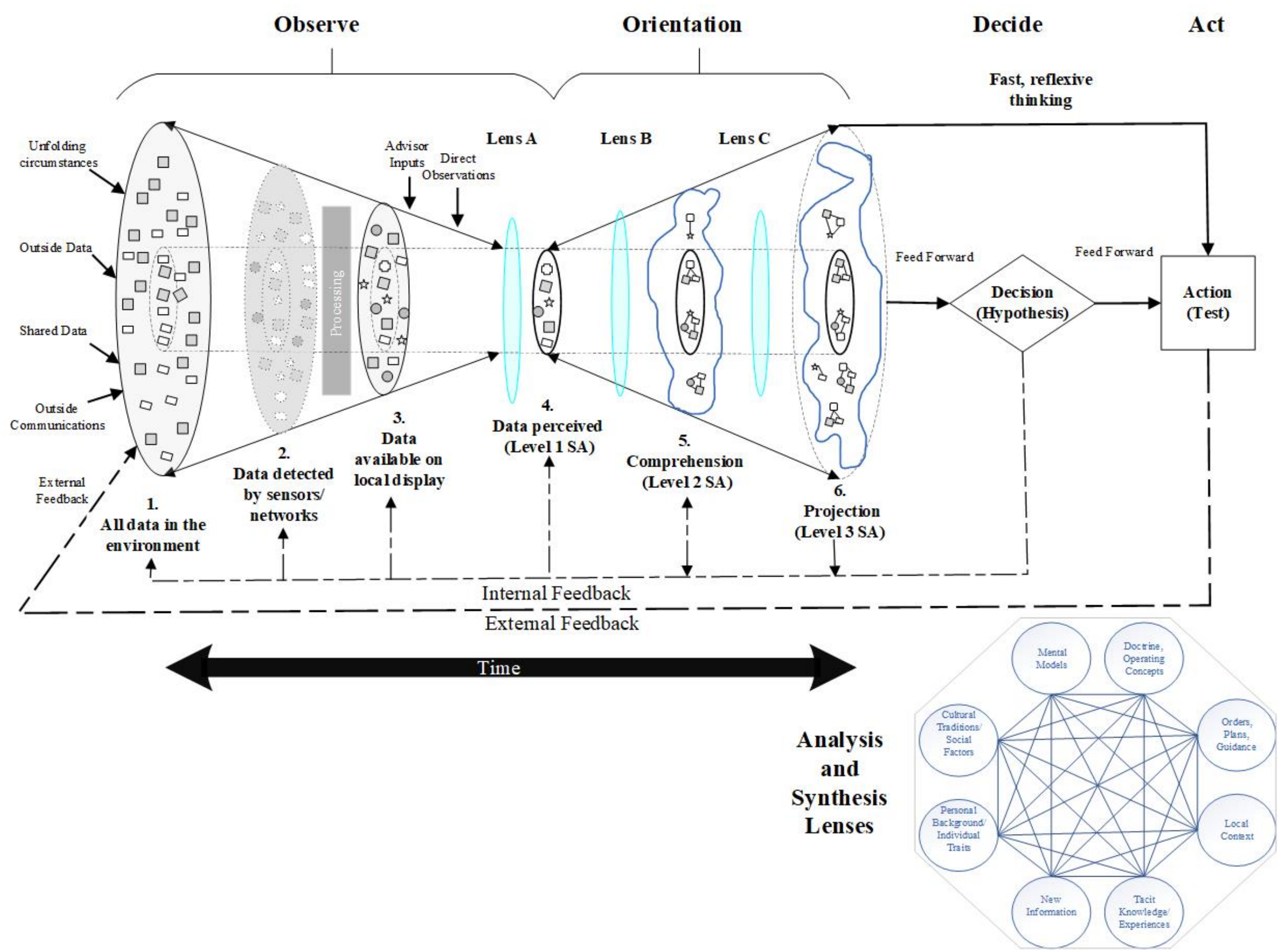

Figure 23. OODA loop 2.0. Adapted from Boyd (2018), Endsley (1995), Hughes & Girrier (2018), Kahneman (2013), Klein (2017), Lawson (1981), Shattuck & Miller (2006).

This detail provides greater granularity to the observation process, which is important in the operating environment. The technological systems portion of the DMSC demonstrates not only the reliance on technological systems, but also how data flows throughout the C2 process. This facilitates insights into ways in which this flow can be interrupted either through adversary operations or through the nature of the operating environment (Brown, 2016; United States Marine Corps, 2021a). This model also incorporates a processing block between Oval 2 and Oval 3. This allows one to visualize not only the need for data processing, but it also effects the speed with which data moves from Oval 2 to Oval 3 and beyond (Phillips et al., 2007).

Included in Oval 1 is all of the data in the environment. Additionally, the model illustrates that items from the original OODA loop such as unfolding circumstances and external feedback are resident in Oval 1. This indicates that one's ability to receive these inputs is predicated on the ability to retrieve them from the environment through Oval 2. Additionally, networked and shared data reside in Oval 1 as well. Once again, the ability to access this data is linked to connectivity provided through Oval 2.

One of the most important aspects of the observation phase is the dynamic nature of Oval 2 as it relates to the environment. Oval 2 is depicted as being partially washed out and surrounded by dashed lines in order to illustrate its ability to grow or shrink based on factors such as network connectivity, OIE, and EMCON. This allows the model to depict the implications of such restrictions as they relate to uncertainty.

As in the original DMSC, this Oval 2 is still a subset of Oval 1. When expanded, Oval 2 captures more of the environment which puts the onus on processing and display capabilities (Oval 3) in order to allow the decision-maker to perceive the information (Oval 3). When reduced, Oval 2 captures less of the environment in Oval 1 which provides limited perceptions to Oval 4.

The idea that orientation can drive observations from the original OODA loop is illustrated by the presence of analysis and synthesis Lens A between Oval 3 and Oval 4. This demonstrates that items such as mission and goals influence what perceptions one pulls from the available information in Oval 3. With the volume and availability of data, it is important to illustrate that only a portion of the available data can be perceived by the decision-maker. This interaction between the technological system and perceptions is analogous to Endsley's (1995) description of Level 1 SA.

2. Orientation

In this model, the perceptual and cognitive system of the DMSC forms the basis of orientation, and the information moves through the model as in the original. Once the information is perceived by the decision-maker, it passes through analysis and synthesis Lens B to provide the decision-maker a comprehension of the meaning of those perceptions in Oval 5. This is similar to Endsley's (1995) Level 2 SA, and Shattuck and Miller's (2006) description of movement through the DMSC.

Once one has a comprehension (Oval 5), the elements of analysis and synthesis (Lens C) provide further meaning to those constructs in order to provide the decision-maker with a projection of the future status of those comprehensions (Oval 6). This is analogous to Endsley's (1995) Level 3 SA.

The lenses of the DMSC are analogous to the implicit cross-referencing conducted during Boyd's orientation phase. As such, the traits of the two models are merged into a larger cross-referencing apparatus that also incorporates traits from Klein (2009). Thus, theses analysis and synthesis lenses include: mental models, cultural traditions and social factors, personal background and individual traits, new information, tacit knowledge and experiences, local context, orders, plans and guidance, and doctrine and operating concepts (Boyd, 2018; Klein, 2009; Shattuck & Miller, 2006). As in the original DMSC, Lens A, B, and C are the same; however, different elements from those lenses would be utilized based on which lens was in use.

3. Decision and Action

The decision and action elements of the model remained largely unchanged from Boyd's model because the existing structure already aligned with elements of NDM and the dual-system model. Fast, reflexive decisions are illustrated by an arrow from orientation direct to action. In these situations, the orientation phase shrinks dramatically because of the System 1 processes (Kahneman, 2013). More deliberate and analytical methods such as System 2 thinking would go through the longer method of orientation, decision and action as depicted. The model also aligns with the RPD model because it incorporates similar cognitive aspects in the orientation phase, while allowing for the simulation of decision options and modifications through hypothesis and feedback. Additionally, the model aligns with Endsley (1995) and Weick (2008) in that the actual decision and action are driven-by yet separated from the cognitive processes of SA and sensemaking. Thus, the projection from Oval 6 is what drives the decision.

4. Feedback Loops

Just as in the original OODA loop, DMSC and RPD, feedback loops play an important role in this model and demonstrate the dynamic and cyclical nature of this model (Boyd, 2018; Klein, 2017; Shattuck & Miller, 2006). Given that the Marine Corps' command and control philosophy is built upon command and feedback, these loops are critical for the C2 system as well as individual decision-making (United States Marine Corps, 2018b). The model illustrates external feedback resulting from actions as an input to Oval 1. This indicates that the primary method of receiving feedback from unfolding interactions with the environment is by sensing the environment. One's ability to receive the feedback portion of command and feedback is dependent on the ability to sense and extract that data from the environment. One can potentially increase tempo by having a more robust system of observations in order to facilitate swift feedback. For example, if one is trying to get feedback from an EABO, they could do so through chat systems, email, radio communications, etc. Those all constitute data elements in the environment that must be sensed through network connectivity or RF comms by Oval 2; however, those methods of communication may not be available due to EMCON or adversary OIE. As such, one would not be able to receive feedback.

Additionally, the internal feedback loops from the DMSC are merged with the decision feedback loop to show that comprehensions, projections, and decisions result in feedback to each preceding oval. In an effort to maintain clarity in the model, the feedback loops to the analysis and synthesis lenses are omitted from the model. To be clear, feedback to the lenses exist as they did in the original DMSC, and once again comprehensions, projections and decisions contribute to updating and altering elements within the analysis and synthesis lenses.

5. Time

Time is critical in the C2 process. As such, this model takes time into account in several places. First, the time arrow beneath the model represents time as it relates to the overall model and the environment. This is in keeping with Boyd's belief that success was gained from operating within an adversary's OODA loop (Boyd, 2018). This remains true; however, one's ability to do so is directly impacted by one's own OODA process. Time is also illustrated by the dual-sided arrows that frame the observation and orientation elements of the DMSC. These represent how aspects of the technological system as well as the perceptual and cognitive system can increase the time to observe and orient due to a variety of reasons. For example, processing delays or network latency can extend the time required to move data throughout the system and delay perceptions. Likewise, uncertainty can cause delays in comprehension and projections, and any feedback or requests for additional information can extend this time.

As in Boyd's original OODA loop, the speed at which one can operate depends upon the rapidity with which one can execute the OODA loop 2.0. When technological systems are incorporated into the model, it demonstrates that that observe-orient process is driven by the speed at which the *system* can receive and process data and how fast the *human operator* can then gain situational awareness from the data received.

6. Networked and shared data

Given the importance of shared data and information in JADC2, it is important to note how such data is represented in the model. This cloud-like connected environment is represented by data residing in Oval 1, and one's ability to retrieve that data is linked to network connectivity in Oval 2. As such, this model illustrates the need for efficient and accurate information-pull so that Oval 3 displays relevant information. Additionally, this can model the effects of contested network communications. If network connectivity is diminished through EMCON or adversary actions, it would shrink Oval 2 and prevent data from moving throughout the model. Additionally, it means that updates to the command concept, intelligence summaries, bulletins, etc., would still need to follow the same path through the system, albeit at perhaps a higher priority, as other information. This is important for Ovals 3 and 4 in that a user must still be able to perceive the information in order to be able leverage it. This could come into play in a time sensitive or chaotic environment where the attention of users is directed elsewhere that an important piece of information could be missed. This has implications should a higher level commander or headquarters need to update the stand-in force (Builder et al., 1999).

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VI. METHODOLOGY

A. VIGNETTE DEVELOPMENT

While there is a historical basis for EABO, there are few cases from modern warfare that can be utilized to describe the C2 challenges of EABO against peer competitors in a potentially degraded information environment. As such this research develops two vignettes based on concepts of employment found in the *Tentative Manual for Expeditionary Advanced Base Operations* (TMEABO). In order to limit the scope, this research examines the C2 challenges of fires in support of surface warfare and fires in support of air and missile defense. The vignettes examine plausible scenarios and the technological systems that will aid decision-makers when operating below the threshold of violence. In order to keep this at an unclassified level, the researcher is deliberately vague with the implementation, capabilities, and limitations with certain weapons and sensor systems. The purpose of this analysis is to use the OODA loop 2.0 to identify issues for consideration when developing C2 systems for EABO.

B. APPROACH

Each vignette includes an overview of the situation as well as purpose of the EAB. The vignettes describe the actual reality present in Oval 1 and then moves through the remainder of the OODA loop 2.0 in order to describe how aspects of that reality move throughout the system enabling the decision-maker to arrive at a decision. The initial iteration describes events in an uncontested information environment. Then, the vignette describes how progression changes based on a denied or degraded information environment. The analysis provides insight into the types of technologies required, specific data required, and the contents of the analysis and synthesis lenses required in order to reach a decision.

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VII. ANALYSIS

A. VIGNETTE 1: FIRES IN SUPPORT OF SURFACE WARFARE

1. Background and Overview

Stand-in forces conducting fires in support of surface warfare serve to counter adversary A2AD capabilities. By applying fires against surface targets, these EABs can help control or deny portions of the littoral operations area (LOA) (United States Marine Corps, 2021). Fires in support of surface warfare can be utilized to help ensure freedom of navigation throughout the South China Sea (SCS) and East China Sea (ECS). China continually engages in increasingly provocative actions to diminish the territorial claims of other countries and claims an overly expansive exclusive economic zone (EEZ) (O’Rourke, 2021b). The use of the China Coast Guard (CCG) and People’s Armed Forces Maritime Militia (PAFMM) constitute a seemingly less menacing way to achieve the same ends. These vessels are able to operate under the guise of enforcing Chinese sovereignty while strong-arming other vessels out of the region (Department of Defense, 2020). The presence of fires EABs can impose greater costs on the Chinese by controlling portions of these disputed areas without the need to have U.S. surface vessels present within the Chinese WEZ. In short, the Chinese would be forced with the prospect of operating within the WEZ of U.S. forces should they wish to continue their salami-slicing actions.

2. Observe

In terms of surface warfare, Oval 1 consists of the ground truth regarding the vessels in the LOA. This includes elements such as nationality, type of vessel, purpose, and intentions. As described by O’Rourke (2021a) and the Department of Defense (2020) the People’s Liberation Army Navy (PLAN) has the capability to employ a variety of vessels from Type 055 cruisers, Type 052 Destroyers, Type 054 Frigates, as well as amphibious vessels as well. Additionally, the CCG and PAFMM can operate in the LOA as well primarily to harass foreign vessels operating in the claimed EEZ. The variety of vessels in Oval 1 means that it would be important for Oval 2 to be able to differentiate between the types of vessels as well as the analysis and synthesis lenses to possess information on the capabilities and limitations of the vessels.

Oval 2 consists of those elements of the vessels in Oval 1 that can be sensed. Some of this data can be provided by a variety of sensors networked to the EAB. This includes active sensing capabilities like surveillance radar, manned platforms, and a variety of unmanned platforms (United States Marine Corps, 2021). These can include a variety of unmanned aerial systems (UAS) such as the MQ-4C Triton, unmanned surface vessels (USV) like Sea Hunter, and smaller organic UAS and USV (Galdorisi, 2021; Sussman, 2020). As such, the employment closely resembles the depiction in Figure 24.

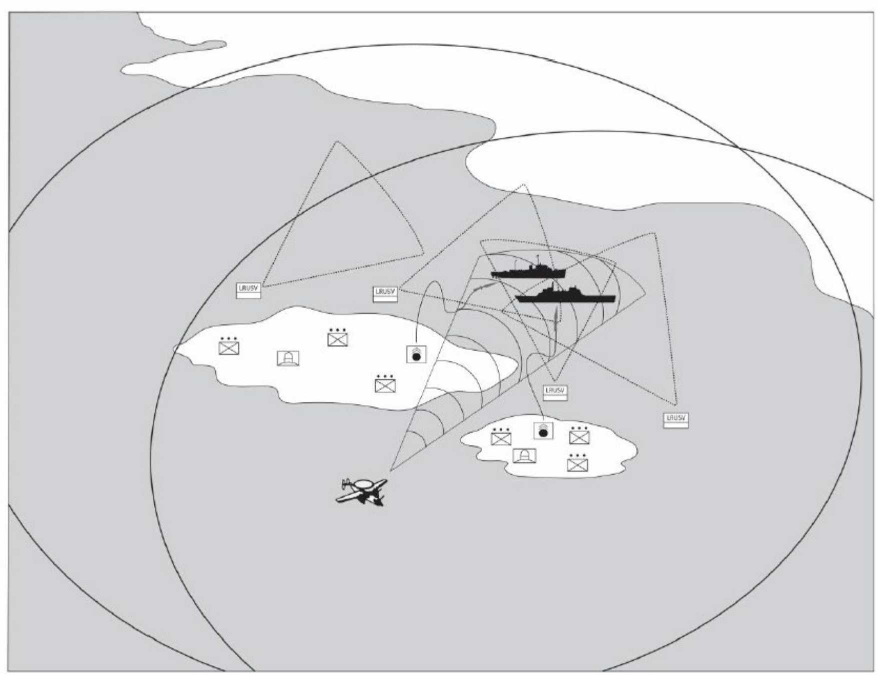

Figure 24. Concept of employment in support of maritime fires.
Source: United States Marine Corps (2021).

One of the advantages of the JADC2 construct is that these sensor assets need not be organic to the EAB, but rather the EAB only requires network connectivity in order to retrieve the feeds from the appropriate system. The data connections could be made by satellite communication (SATCOM) or through advances in the mobile ad-hoc network (MANET) throughout the LOA (Bordetsky & Netzer, 2010). Through this network, surface and airborne nodes, on manned and unmanned platforms, could create a resilient network throughout the area (Markray & Waller, 2018; Maupin, 2016). Network connectivity also enables access to systems such as the automatic identification system (AIS), so the EAB could use AIS data to help determine the identity and intentions of the vessel.

The EAB's communication capabilities are also a component of Oval 2 because it enables them to receive inputs sent via RF channels from other stand-in elements as well as higher headquarters. This suite could include high frequency (HF), very-high frequency (VHF), ultra-high frequency (UHF), SATCOM, as well as the previously mentioned data connections enabling it to be linked into the JADC2 cloud. By enabling multiple channels of communication, friendly forces could communicate in a variety of ways should one become inoperative. It also helps complicate adversary EMSO and distributes the bandwidth requirements across multiple systems. When taken together, the combination of sensing, networking, and communication capabilities creates an expanded Oval 2. This capability enables the EAB to pull more data from Oval 1.

In this specific scenario, Oval 1 consists of a *Renhai* (Type 055) cruiser transiting at high speed to intercept a disabled U.S. survey vessel. Additionally, a flotilla of PAFMM vessels is transiting to contested fishing waters that are being utilized by third-country fishermen. Each of these vessels could be sensed by various unmanned systems in the surveillance area. Because of the robust sensing capability, Oval 2 could detect the cruiser as well as its direction and speed. The survey vessel could be detected via AIS and radio relays allowing the EAB to receive the radio messages sent via maritime distress frequencies. Oval 2 could detect the flotilla of fishing boats transiting towards the contested fishing area; however, there was not a way to directly sense whether or not they were PAFMM.

Because these two situations are developing in different areas, it puts a limit on what can be perceived (Oval 4) at any given time. This limitation could be in part to display limitations. If the decision-maker only has the ability to display one feed at a time, they would be forced to rotate between feeds. Even if the decision-maker could monitor both at the same time, their attention would be split between the two developing situations. In either case, there would be elements from Oval 3 that did not progress to Oval 4. In this case, the decision-maker can only monitor one situation. Given the mission of the EAB, their Lens A directs their attention towards the situation regarding the cruiser, so the decision-maker is no longer monitoring the PAFMM vessels.

3. Orient

In the case of the cruiser, the decision-maker's Lens B would help provide meaning to the perceptions in order to comprehend what the cruiser was doing. The combination of perceptions allowed the decision-maker to comprehend that the cruiser was transiting to intercept the survey vessel. Because the decision-maker had a basic understanding of ship's transit speeds, they concluded that the cruiser was transiting above a normal cruising speed. Because the survey vessel's messages did not indicate any need for *immediate* assistance, the decision-maker concluded that the cruiser was trying to get there before U.S. vessels or assets could respond.

Having come to this Oval 5 comprehension, analysis and synthesis Lens C provided more context that may project the intent of the vessel once it reaches the survey ship. Because the cruiser was not responding to the survey vessel over the maritime distress frequency, the decision-maker was concerned that they may have some nefarious intentions once they reach the vessel, especially because it was located in the expanded Chinese EEZ. Based on this Oval 6 projection, the decision-maker provided feedback to the observation phase to try and gain more information regarding movements of other Chinese assets.

4. Decide and act

Based on the orientation in Oval 6 of the cruiser, the decision-maker did not perceive the necessary hostile acts or hostile intents that would enable them to fire on the cruiser. However, the decision-maker put information into the environment (Oval 1) by reporting what they were seeing to the SUWC. This would enable higher echelons of command to sortie other assets to the area to assist. It would also give higher headquarters the opportunity to order the EAB to fire on the cruiser, based on their own analysis of the situation. As the situation continues to develop, the decision-maker can look for cues that could indicate any hostile acts or intents from the cruiser.

One's decision and action would also be based on the methods at their disposal to alter their environment which come down to weapons and communication systems. A future fires EAB would likely deploy with the Navy Marine expeditionary ship interdiction system (NMESIS) providing an over-the-horizon targeting capability utilizing the naval strike missile (NSM) (Shelbourne, 2021; Wood, 2021). The NSM has a range of approximately 100 NM and "combines a GPS-aided multi-sensor navigation suite with an advanced dual-band imaging infrared seeker with autonomous target recognition for terminal guidance" (Scott, 2015). As depicted in Figure 24, this targeting information could be provided by the previously mentioned manned and unmanned sensor systems. While this system would enable the decision-maker to fire upon the cruiser, that is not yet the prudent course of action. As such, it is important for the EAB to communicate with higher headquarters to ensure more capable assets are able to respond to the situation.

Communicating with adversaries can be viewed as a feasible action for scenarios that fall beneath the threshold of violence. In this case, if the decision-maker had the ability to do so, they could issue warnings to the cruiser to stay away from the survey vessel. This could serve to develop the situation further and help determine their intents. This also puts a C2 strain on the Chinese cruiser. Knowing that they are within the WEZ of a U.S. system may preclude them from taking aggressive actions.

5. Time

Time plays a factor in this situation because of the ability of friendly forces to respond. The decision-maker quickly needs orient on the situation and inform higher, so there is time for assets to be sortied and sent to the area. If the situation were to unfold close to the maximum sensing range or weapon's range, time could be a constraint in that the decision-maker would need to act before the cruiser was out of range.

6. Analysis and synthesis lenses

The OODA loop 2.0 can help identify key information that must be present in the analysis and synthesis lenses in order to accomplish the mission. In this scenario, it is important that aspects of surface warfare be present in the analysis and synthesis lenses of the decision-maker. This is a more complex scenario than simply an ashore call for fire. In this case one must contend with maritime laws and customs. It is also important that they receive updated command concepts and information on recent incidents with Chinese vessels in order to help the decision-maker drive perceptions, and apply meaning to those perceptions. If, for example, the decision-maker read an intelligence update that PLAN vessels directed to take aggressive actions against vessels in the EEZ, it would impact how they comprehended and projected the actions of that cruiser.

One of the most important aspects of the analysis and synthesis lenses is the presence of mental models. This being a relatively new mission set, it would be important to instill mental models within the decision-maker's lenses. This could be accomplished through training exercises designed to mimic adversary procedures.

7. Contested Environment

The Chinese possess a variety of methods to deny or degrade the information environment. This includes communications jamming and electronic countermeasures aircraft like the Y-9, and unmanned systems and surface vessels with similar capabilities (Department of Defense, 2020). These systems could be used to hinder feeds from unmanned systems as well as communications capabilities. Additionally, conventional Chinese assets could be utilized to destroy or disable unmanned systems serving as MANET nodes assets thereby reducing the effectiveness of the network. The bottom line is that these actions would shrink the capabilities of Oval 2 which can significantly limit the information available to the decision-maker.

In this case, the Chinese damaged unmanned surface MANET nodes causing the EAB to lose their link to the JADC2 cloud. Additionally, a Y-9 in the region is jamming the EAB's communication capabilities; however, the EAB is still able to receive it's UAS feeds.

With this reduction in Oval 2, the decision-maker could still perceive the Chinese cruiser as well as its speed and direction through the drone feed. However, because of the jammed communications and disabled network, the decision-maker cannot sense the disabled survey vessel. As such, from this incident, the cruiser transiting at higher speeds is the only item that becomes a perception. Using their knowledge of transit patterns, they could comprehend they are traveling somewhere in a hurry, but they would have no idea why that would be. Based on the lack of contextual cues, it would be difficult to project anything besides that they will continue to transit (Oval 6). Thus, there is not really a decision to be made.

Losing the ability to communicate is important because it prevents the EAB from informing the SUWC, and prevents the SUWC from issuing further direction to the EAB. Because communications are jammed, they would not be able to notify higher headquarters of the ship's actions. This would prevent higher headquarters from sortieing assets to aid the survey vessel. It could also be possible that higher headquarters had different information at their disposal which indicated the cruiser having hostile intent. If it was the desire of the SUWC to have the EAB fire on the cruiser, they may not have had the capability to do so based on the jamming techniques.

8. Summary

From this vignette, it is clear that available technologies can create an expansive Oval 2 that can sense more of the environment in Oval 1 and provide the decision-maker with a variety of perceptions. But there still limits as to what can be sensed by even the most advanced platforms. The key component in this scenario is still the decision-maker's ability to orient upon those perceptions in order to infer what the human operators of the vessel are doing or what they intent to do. Advanced sensing can aid this, but the components of the analysis and synthesis lenses are what enables the decision-maker to piece those perceptions together to formulate the SA and orientation.

A communications denied or degraded environment would shrink Oval 2 in unpredictable ways, since the exact effects would be based on the specific electronic attack techniques utilized by the adversary. Having a limited capability to sense potential targets or receive targeting data, the EAB would have a limited capability to engage targets and fulfill their mission. If a decision-maker is not aware of their limitations in such a degraded environment, it is certainly possible for the right series of events to occur that certain perceptions align with a mental model that causes a decision-maker to arrive at a decision to fire when they should not, or failed to fire when they should.

B. VIGNETTE 2: AIR AND MISSILE DEFENSE

1. Background and overview

In this instance, a littoral force is used to provide air and missile defense (AMD) against Chinese missile threats in the littoral operations area (LOA) (United States Marine Corps, 2021). This is an important mission because these longer range missile threats are the weapons that increase the size of the adversary WEZ. These weapons necessitate stand-in forces because the missiles must be sensed and engaged as early as possible in order to mitigate their range and speed (Hughes & Girrier, 2018). Figure 25 illustrates how the use of AMD could be used to protect surface vessels. While not depicted in the figure, indications are that the Chinese would utilize volleys of missiles in order to overwhelm ships defenses (Gormley et al., 2014b). This includes deploying a variety of missiles with different flight profiles and speeds in order to strain defenses and limit the reaction time of the targeted vessels (Gormley et al., 2014a).

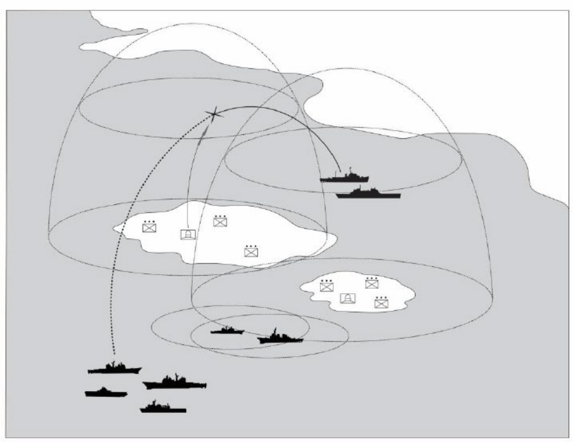

Figure 25. Notional AMD EAB concept of employment. Source: United States Marine Corps (2021).

The goal of these AMD EABs would be to reduce the effectiveness or destroy hostile air and missile threats (United States Marine Corps, 2021). While much attention is paid to the Chinese missile threat, it is also important to note that these EABs could play a critical role in addressing the Chinese air threat.

2. Observe

Oval 1 could include ships or aircraft operating in the area capable of firing ASCM or other missiles. In this example Oval 1 consists of two *Luyang III* (Type 052D) destroyers as wells as three H-6Js bombers.

Oval 2 would require the ability to sense those platforms as well was a missile launch from those platforms. While it is relatively easy to sense the platform, it is more difficult to determine when a missile has been launched (Brose, 2020). Most modern missiles utilize offboard targeting data and inertial navigation systems (INS), so one would not detect emissions from a fire control radar since it would not be in use (Heginbotham, 2015). Space-based sensing systems are not designed to detect the launch-plumes of cruise missile engines and motors (Gormley et al., 2014b). It may be possible to detect the launch by detecting the infrared energy from the rocket motor through sensor systems similar to those on aircraft survivability equipment; however, the sensor would need to be close to the missile. The missiles could also be detected by radar; however, cruise missiles have a very small radar signature and when combined with supersonic speeds and very low altitudes, they can be difficult to detect (Gormley et al., 2014b). It is certainly possible to detect incoming missiles; however, as demonstrated, it is difficult to detect. Thus, of the data available in Oval 1, there is a very limited amount available to the decision-maker.

The speed and range of adversary air and missile threats necessitates having a series of AMD EABs throughout the LOA that can leverage joint and organic sensors through the data sharing capabilities of JADC2 (United States Marine Corps, 2021). This expands the data available in Oval 2 and can potentially increase the decision-space of decision-makers. For example, the launch could be detected by a more forward EAB, the data transmitted throughout the LOA, and a more rearward EAB, or even a surface vessel, could leverage the early warning to launch an interceptor.

The challenge for the decision-maker is being able to display inputs from these data sources in a coherent manner (Oval 3). This is certainly possible; however, it requires thorough interoperability between platforms promised by JADC2. Based on the mission of AMD, the decision-maker's analysis and synthesis lenses can focus their attention on *potential* threats such as those displayed platforms that are known to be capable of carrying ASCM.

3. Orientation

From those perceived potential threats in Oval 4, the decision-maker would utilize their analysis and synthesis lenses to comprehend what the adversary ships and aircraft were doing (Oval 5) and project what they may do (Oval 6). This is one of the primary challenges of the orientation phase for the decision-maker because Chinese aircraft operating in the region is not necessarily an indication that they are about to launch a strike against U.S. forces. Thus, they can direct internal feedback to the observation phase to attempt to find other cues that could indicate hostile intent or hostile actions. This could include retrieving shared data from the environment to include hostilities in other areas of the AO, updated intelligence reports, or tracking other ship and aircraft activity outside of their LOA. In a networked environment, it could also include messaging forward sensor EABs to direct their attention to a certain area thus expanding and refining Oval 2 in the observation phase.

When conducted and AMD EAB when operating below the threshold of violence, it is difficult to orient on the adversary. In the case of the three bombers, the decision-maker can use their analysis and synthesis lenses to recognize that the H-6J can carry six supersonic long-range YJ-12 ASCMs that are capable of reaching targets to the Second Island Chain (Department of Defense, 2020). When outfitted with its payload, these aircraft are certainly a threat; however, their mere presence does not constitute a hostile act or hostile intent that would warrant shooting them down prior to the H-6J firing first. The same could be said of the two destroyers, while an analysis and synthesis lens could tell the decision-maker that the *Luyang III* can carry the YJ-18 which in addition to being a long-range supersonic ASCM can rapidly maneuver at up to 10Gs in order to avoid interception, once again, their mere presence does not constitute hostile acts or intents (Heginbotham, 2015).

Applied to the OODA loop 2.0, the presence of the platforms and their capabilities can be comprehended by the decision-maker in Oval 5. It is inherently difficult to judge their future status because there are few indicators of a pending launch. Thus, the decision-maker would likely need to continually monitor these platforms and wait for an overt sign of a hostile act or hostile intent.

4. Decision and action

In the case of a perceived missile launch, there is not much of a decision for the decision-maker to make. In this case, they would execute the fast reflexive thinking and immediately authorize the launch of an interceptor missile. The exception to this would be if they were able to detect a launch, but came to the quick orientation that the geometries were such that they could not fire to intercept the missile.

It is more difficult to judge hostile intent and launch a pre-emptive attack which is one reason why constant connectivity to the Air and Missile Defense Commander (AMDC) would be important. In situations that may require pre-emption or even uncertainty, the decision-maker can push these questions to higher echelons of command and await their feedback. Pushing such scenarios to higher echelons also allows them to sortie friendly aircraft or utilize other assets to aid in the situation as well.

Communicating with adversaries is also important in this scenario. It is an important action for a decision-maker to be able to warn adversary aircraft if they are conducting operations that appear to be threatening. Such warnings can allow the decision-maker to ascertain the intentions of the adversary, and potentially expand their decision-space. This too has a limit though. With most Chinese missiles having ranges in the hundreds of nautical miles, it is not reasonable to force adversary platforms to remain outside of the engagement envelope of these missiles.

5. Feedback

Feedback plays an important role in this scenario because as these situations develop, the decision-maker will have to constantly provide feedback to network and sensor systems in order to search for cues that would indicate hostile intent or hostile acts. It is also critical to provide feedback as data into Oval 1 so that other friendly assets can access it through their Oval 2. This is especially important in the event of missile launch so that other assets in the LOA can respond as appropriate.

6. Time

Time is of paramount importance in this type of operation because of the speed at which ASCM travel. In the case of high supersonic and hypersonic missiles, not only is there limited time in order to perceive and act, but one must also do so in such a time that allows the intercepting missile to actually intercept the target. Thus, after missile launch, the OODA loop 2.0 must turn very quickly.

Because of the need for rapidity, it is important that the interoperability and processing capabilities of all systems involved with this in mind. If data shared from other entities must go through time consuming processing, it could make a difference whether a missile is launched in time or not.

7. Analysis and synthesis lenses

It is important that decision-makers be intimately familiar with adversary weapons systems so that they can direct their attention (Lens A) appropriately and can correctly comprehend and project based on their observations. This systems knowledge when combined with knowledge of adversary tactics and the local context can develop and trigger mental models that will aid in comprehending and projecting what is occurring.

This scenario also necessitates thorough command concepts and orders that cover contingencies to the best of planners' abilities. This can provide direction to the decision-maker when faced with some uncertainty.

8. Contested Environment

The ability to effectively conduct AMD can be severely impacted in a contested environment. While Oval 1 would remain the same, the ability to detect those actions in Oval 1 diminishes as Oval 2 shrinks. This can occur through adversary OIE that impact forward sensor EABs, network connectivity, communication from unmanned systems, the AMD EAB, etc.

For example, if one's capacity to detect the destroyers and bombers is impacted (Oval 2) then the decision-maker could not perceive their presence and prime the system to look for cues of a launch. Without the ability to detect the platform, the first indications one may receive of the platform could be from launch indication sensors or the active homing of the missile itself, which would limit the decision-maker's response capability.

Conversely, if network connectivity between EABs was degraded, it would make it difficult to exchange data regarding launch indications. This would degrade the ability for forward EABs to push the data to more rearward EABs that could actually intercept the missile. Once again, if the decision-maker cannot perceive the launch data, they cannot take the necessary actions to intercept the missile.

An environment where communications are impacted would prevent the decision-maker from pushing requests for information and authority to fire up through the chain of command. Thus, they could be left to their own decision-making capacity based on the rules of engagement to fire.

One of the benefits of JADC2 in this instance is that with systems being interconnected, another EAB or entity could continue the mission should one EAB be affected. In other words, redundancies in the system could allow other stand-in forces to receive the information. Geometries of fire can limit this in such a way that while those EABs could come to the correct orientation of what is going on, they may be powerless to take action because they are not in a position to intercept the missile.

9. Analysis

AMD EABs provide a valuable warning and defense capability given the threat of adversary missile systems. However, as this vignette demonstrates, this is not an easy mission. The OODA loop 2.0 helped illustrate the sensing limitations that make defending against extremely low altitude supersonic missiles difficult. These limited inputs make orientation difficult. One could correctly comprehend what is currently occurring in the environment (Oval 5), but it would be difficult to correctly project this comprehension into the future. As the vignette demonstrated, dangerous threat systems with ASCM loadouts could be operating in the environment, but there are relatively few cues that could lead to an accurate projection that they intend to engage. This prospect becomes more daunting in a denied or degraded information environment as those few cues are no longer available due to a shrinking Oval 2.

VIII. SUMMARY AND FUTURE WORK

A. CONCLUSIONS

Boyd's original OODA loop represented a way of thinking about thinking, and this research sought ways to update that manner of thinking in order to be effective in the current operating environment given the reliance on technological system. This is important because decision-making and the OODA loop are at the center of command and control. Despite the emphasis on technological systems, those systems exist to facilitate the flow of information to the decision-maker so that they can make a decision. Despite advances in sensor technology and networking, there are still limits to what can be sensed and present in Oval 2. While it is possible to sense tangible events and cues, it is difficult, if not impossible, to sense the intentions of platforms. The onus is still on the decision-maker to fill these gaps through orientation. It is the decision-maker's orientation that will determine whether ships and aircraft are merely harassing friendly forces or whether they actually have hostile intents.

In the realm of competition, the link between observations and orientation becomes even more critical. As one's networking and sensor capabilities increase, one can have more observations to feed orientation. However, simply because one has more observations does not equate to making a better decision. The key lays in the orientation phase where those perceptions are analyzed and synthesized in order to comprehend the situation and project the future status of those events. Given the composition of the analysis and synthesis lenses, different decision-makers my highlight certain perceptions and subsume others based on those traits, which can lead to varying comprehensions and projections.

Technological systems impact decision-making by providing the cues and observations to the decision-making process; however, these systems have their limits. In an uncontested environment, modern networking and communications techniques leave the bounds of information sharing nearly limitless. While this is in keeping with the tenants of NWC, the decision-maker must be able to parse through the available data to determine what they actually perceive and what continues through the model. Just because it is available does not mean it is perceived. The composition of one's analysis and synthesis lenses affect what is perceived. When the information environment becomes contested, as OODA loop 2.0 demonstrates, the ability to extract information from the environment diminishes, sometimes in unpredictable ways. This limits the amount of data that can flow through the model and can lead to uncertainty. In the absence of information, the decision-maker must fill those gaps in order to attempt to comprehend and project the environment.

The decision-making models described in Chapter II are important to the study of command and control because such models attempt to illustrate how decision-makers determine what must be accomplished and see to its execution. Like Boyd, these theories emphasized the importance of orientation in its various forms, because it is that orientation that leads to decisions and actions. Several of the models discussed conceded that technological systems impacted the orientation process through the availability of environmental cues, but failed to delve into those specific impacts. In other words, the DMSC was one of the few models that directly addressed the impacts of technological systems to provide those cues.

Most importantly, in EABO it is not enough to simply think of observations as an end product. Instead, observations are a process facilitated by technological systems as demonstrated by the OODA loop 2.0. The observation phase is a complex technical process involving the sensing and processing of the environments and displaying that to the decision-maker. This fidelity enables one to examine the data in the environment itself, the ability to sense the data, the ability to display the data or manipulations of the analysis and synthesis lenses in order to manipulate what is perceived by the decision-maker. The character of competition and warfare against peer competitors necessitates this level of fidelity.

The researcher initially expected the analysis to show that technological systems shifted some of the importance of the orientation phase to the observation phase of the OODA loop. Instead, technological systems merely strengthen the relationship between observations and orientation, and perhaps even make orientation even more important. In fact, due to varying amounts of data available from Oval 2, orientation becomes even more critical as a decision-maker must develop SA, in line with the true environment, when contending with a deluge of information as well as limited and degraded information.

B. ADDITIONAL FINDINGS AND LIMITATIONS

Due to the scope of this research, most of the emphasis on C2 systems focused on the technological aspect; however, the fact that technological systems encompass just one part of the overall C2 system cannot be overstated. In fact, it may be possible to compensate for the limitations of technological systems in a contested environment through thorough planning and contingencies.

Because EABO are a relatively new concept that is still being tested, the greatest limitation of this research was the limit of historical case studies that capture both the technology and contested information environment that EABO are designed to operate within. This caused the researcher to expand upon concepts outlined in the TMEABO in order to develop the vignettes. While not ideal, the vignettes illustrated the validity of the model as well as points of contention within the operating concepts.

C. RECOMMENDATIONS FOR FUTURE WORK

OODA loop 2.0 can facilitate future studies in AI by analyzing where narrow AI outputs fit into the model to impact human decision-making in order to better align the human-machine team. If narrow AI and ML algorithms are to be used as decision aids, humans would still need to make the final decisions. If humans act in an on-the-loop capacity, that individual would conceivably need to come to some sort of orientation and decision in order to determine the best course of action: to approve the action or veto it. In doing so, OODA loop 2.0 can help expose issues in C2 systems to be addressed either through organizational structures or procedures in order to make best use of the technology.

It is not only important to exercise the concepts within the TMEABO but those exercises must strain the decision-making capability of the decision-maker. OODA loop 2.0 could be used to help design those exercises by identifying how to manipulate the environment. This could include utilizing OIE to impact observations by manipulating Ovals 1–3, the analysis and synthesis lenses, and the ability to receive feedback. Examining these can expose the needs for other sensor capabilities and weapons capabilities that may increase a decision-maker's decision space. Results from these exercises could also drive the need for organizational or procedural changes that are designed to mitigate the effects of a contested information environment.

OODA loop 2.0 provides an expanded and more tangible view of the traits present within the orientation phase through the analysis and synthesis lenses. Future work can be conducted in order to determine what needs to be present in the decision-maker's analysis and synthesis lenses for EABO mission sets. For example, if Marines are to conduct fires in support of surface warfare, how much resident knowledge must they possess regarding surface warfare and naval tactics? This could result in organizational adjustments such as providing the stand-in force with an on-sight naval liaison in order to provide some of that knowledge.

The Naval Postgraduate School Center for Network Experimentation (CENETIX) could utilize this model to design experiments utilizing the networking technology previously discussed during an experiment. For example, a MANET network could be constructed and then degraded utilizing a variety of jamming and interference techniques. This would create an environment of variable Oval 2s from which decision-makers could be driven to make decisions. This could help determine not only the effectiveness of decision-making under such conditions, but also help determine what data points are the critical ones that helped make decisions.

While the vignettes go into a few examples of EABO, the reality is that when utilized there will be varying types of EABs across the LOA that, in an uncontested environment, would be networked with Naval forces as well as those from the Army and Air Force. This is what JADC2 envisions. What comes out of this research though is a need to address issues of shared situation awareness, and how, when using this model, decision-makers interact with other decision-makers in the LOA. If one assumes that the components of a Marine's analysis and synthesis lenses are different from a surface warfare officer or an Air Force pilot, then by extension their orientation's may differ.

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