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ENGINEERING DECISION-CENTRIC AVIATION OPERATIONS FOR EXPEDITIONARY ADVANCED BASE OPERATIONS

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THESIS

ENGINEERING DECISION-CENTRIC AVIATION OPERATIONS FOR EXPEDITIONARY ADVANCED BASE OPERATIONS

by

Juan T. Valencia

June 2024

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This thesis investigates the implementation of Decision-Centric Warfare (DCW) principles within Marine Corps Aviation to enhance decision-making processes in high-stakes environments. It explores the integration of advanced automated systems and artificial intelligence in supporting command, control, and communications crucial for operating under emission-controlled, denied, or degraded scenarios. The study emphasizes the role of human-machine teaming and the critical application of causal logic in AI systems to improve the transparency and effectiveness of decision-making. Through a detailed analysis of vignettes reflecting current and future operational capabilities, the research identifies key strategies for maintaining decision superiority against adversaries by leveraging technology to expedite and enhance operational planning and execution. This work contributes to the broader military objective of achieving a decision advantage in dynamic and contested operational contexts, aligning with the goals of Force Design 2030 and Expeditionary Advanced Base Operations.

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ENGINEERING DECISION-CENTRIC AVIATION OPERATIONS FOR EXPEDITIONARY ADVANCED BASE OPERATIONS

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This thesis investigates the implementation of Decision-Centric Warfare (DCW) principles within Marine Corps Aviation to enhance decision-making processes in high-stakes environments. It explores the integration of advanced automated systems and artificial intelligence in supporting command, control, and communications crucial for operating under emission-controlled, denied, or degraded scenarios. The study emphasizes the role of human-machine teaming and the critical application of causal logic in AI systems to improve the transparency and effectiveness of decision-making. Through a detailed analysis of vignettes reflecting current and future operational capabilities, the research identifies key strategies for maintaining decision superiority against adversaries by leveraging technology to expedite and enhance operational planning and execution. This work contributes to the broader military objective of achieving a decision advantage in dynamic and contested operational contexts, aligning with the goals of Force Design 2030 and Expeditionary Advanced Base Operations.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACE	air combat element
ADGR	air-delivered ground refueling
AI	artificial intelligence
APA	advance planning agent
AR	air reconnaissance
AS	assault support
C2	command and control
C3	command, control, communications
COA	course of action
COAM	control of aircraft and missiles
CONOPS	concept of operations
DAO	distributed aviation operations
DARPA	Defense Advanced Research Projects Agency
DCAO	decision-centric aviation operations
DCW	decision-centric warfare
D-DIL	denied-disrupted, intermittent, limited
DIKW	data, information, knowledge, wisdom
DIKU	data, information, knowledge, understanding
DOD	Department of Defense
EAB	expeditionary advanced base
EABO	expeditionary Advanced Base Operations
EMCON	emissions control
EW	electronic warfare
FARP	forward arming and refueling point
FVL	future vertical lift
HDST	hybrid decision support tools
HMT	human-machine teaming
HQ	headquarters
HQMC	Headquarters Marine Corps

I&W	indication and warnings
LAW	light amphibious warship
LZ	landing zone
MAG	Marine aircraft group
MAGTF	Marine air ground task force
MCPP	Marine Corps planning process
MCDP	Marine Corps doctrine publication
MCWP	Marine Corps warfighting publication
MEU	Marine expeditionary unit
ML	machine learning
MLR	Marine littoral regiment
MSA	mission support agent
NLP	natural language processing
NML	non-monotonic logic
OPD	observability, predictability, and directability
OODA	observe-orient-decide-act
PEL	precautionary emergency landing
PRC	People's Republic of China
R2P2	rapid response planning process
SA	situation awareness
SIF	stand-in forces
SPOTR	surveillance, persistent observation, and target recognition
TADIL	tactical digital information link
TM	tentative manual
UAS	unmanned aerial system
ULS	unmanned loitering system
USMC	United States Marine Corps
WEZ	weapon engagement zone

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I. INTRODUCTION

> At first glance, war seems a simple clash of interests. On closer examination, it reveals its complexity and takes shape as one of the most demanding and trying of human endeavors. War is an extreme test of will. Friction, uncertainty, fluidity, disorder, and danger are its essential features. War displays broad patterns that can be represented as probabilities, yet it remains fundamentally unpredictable. Each episode is the unique product of myriad moral, mental, and physical forces. Individual causes and their effects can rarely be isolated. Minor actions and random incidents can have disproportionately large – even decisive – effects. While dependent on the laws of science and the intuition and creativity of art, war takes its fundamental character from the dynamic of human interaction. (United States Marine Corps [USMC], 1997, pp. 19–20)

This thesis analyzes decision-making and applies Decision-Centric Warfare (DCW) concepts to Marine Corps aviation and operations. DCW focuses on increasing the speed of the decision-making process and giving leaders options to gain a decision advantage over their adversary. By implementing force design, automated systems, and enhanced command, control, communications (C3) supported by human-machine teaming and artificial intelligence, a decision advantage can be leveraged in an emission controlled, denied, degraded environment. Decision-Centric Warfare comes at an important time, as the United States Marine Corps (USMC) realigns itself to meet Force Design 2030 objectives as well as future operating concepts such as Expeditionary Advance Base Operations (EABO). This thesis advances a framework on how to engineer Decision-Centric Aviation Operations (DCAO) for the Marine Corps and apply those functions and warfighting concepts for the future.

A. PROBLEM DESCRIPTION

Network-centric warfare made its worldwide debut during the first Gulf War in 1991. The world watched as sophisticated United States (U.S.) aircraft dropped laser guided munitions on targets across Iraq with deadly precision while coordinated with rapid ground movements and combined arms. The technological advances in warfare and operational concepts carried out by the U.S. military demonstrated the new evolution of warfare on the horizon, while allies and adversaries observed. However, the United States' military advantage that was rooted in technology has diminished due to the proliferation of technology in stealth, precision weapons, and communications developed across the world (Clark et al., 2020, p. i).

Since the Gulf War, near peer adversaries such as the People Republic of China (PRC) and the Russian Federation have learned from the United States and have adapted their tactics, techniques, and procedures accordingly. Both countries have developed and fielded advanced sensor networks and weapons that are integrated into system of systems designs that are developed to target and put at risk U.S. capabilities. Complementary to their advances in technologies, the PRC and Russia have utilized proxy forces to carry out gray zone operations to influence the territories around them. To address these advances in technology, the United States must develop new operational approaches to counter the new challenges of great power competition (Clark et al., 2020, p. ii).

A crucial goal in any conflict is maintaining an advantage over the adversary's decision-making cycle, outpacing their leaders and executing actions one-step ahead. As in any previous conflict that the Marine Corps has been involved in since World War I, Marine aviation has played a key role in supporting ground force maneuvers and EABO littoral operations will not be any different. In a conflict with a peer adversary, it is anticipated there will be degradation of C3 systems and the U.S. Naval Service will be required to operate efficiently in an emission control (EMCON) or denied-disrupted, intermittent, limited (D-DIL) environment. Marine aviation will need to develop a framework for DCAO, to maintain decision superiority through the adversary's attempts to degrade U.S. forces.

B. PURPOSE

The purpose of this thesis is to increase understanding of how context and information affects decision-making actions when engineering DCAO for Marine Corps aviation.

C. RESEARCH QUESTIONS

1. How can the Marine Corps engineer decision-centric aviation operations?

2. How does information and context affect decision-making?
3. What decisions in the planning process support the ability to gain a decision advantage?
4. How can artificial intelligence and other automated systems be leveraged to support decision-making?

D. THESIS ORGANIZATION

This thesis is broken into five sections: an introduction, literature review, methodology, analysis, and conclusion. The literature review will provide background information on the topics of Marine Corps warfighting concepts, Marine Corps aviation, decision-making, data fundamentals, Decision-Centric Warfare, data to wisdom transformation, artificial intelligence, and human-machine teaming. The literature review also provides the necessary information for the analysis and provides context for research on decision-making. The methodology section will describe how vignettes are used to analyze the aviation planning process and decision-making within the context of planning for EABO and executing aviation operations. The analysis section uses two vignettes to evaluate effective decision-making through the lens of modern-day military operations and compares the decision-making methods to future DCAO ideas. In the conclusion, recommendations are made for near-term improvements as well as follow on research opportunities.

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II. LITERATURE REVIEW

A. CHAPTER OVERVIEW

The literature review provides background information on the topics fundamental to Decision-Centric Aviation Operations, such as the Marine Corps' warfighting concepts, Marine Corps aviation, decision-making, data-essentials, Decision-Centric Warfare, data to wisdom transformation, artificial intelligence, and human-machine teaming.

B. EXPEDITIONARY ADVANCED BASE OPERATIONS

This section introduces the central idea of the Marine Corps' new operational concept, called Expeditionary Advanced Base Operations (EABO) and Stand in Forces (SIF).

1. Operational Concept

The Marine Corps' 2023 *Tentative Manual (TM) for Expeditionary Advanced Base Operations* describes EABO as:

> A form of expeditionary warfare that involve 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 sea denial, support sea control, or enable fleet sustainment. (USMC, 2023, p. 1-2)

The intent of EABO is to "contribute to integrated deterrence through Marine Forces that are structured and ready to persist, partner, survive, and fight effectively across an expanded maneuver space as a ready, capable, and combat-credible forward force" (USMC, 2023, p.1-3). This contribution would occur in the support of a naval campaign and not to only serve Marine Corps' operations.

2. Stand in Forces

Defined in the *TM for EABO*, Stand in Forces (SIF) are:

> Mobile, low-signature, persistent, and relatively easy to maintain and sustain naval expeditionary forces designed to persist and operate inside a

> competitor's weapons engagement zone to cooperate with partners, support host nation sovereignty, confront malign behavior, and, in the event of conflict, engage the enemy in close-range battle. (USMC, 2023, p. E-7)

SIF will be the Marines operating and existing within the adversary's weapon engagement zone (WEZ). These Marines will conduct sea denial alongside partners and allies and will be capable of being the eyes and ears for the naval and joint force in support of a naval campaign (USMC, 2023, p. 1-1). However, in order for Marines to be a successful SIF, their ability to be mobile, persistent, and low signature will require an equally capable stand-in aviation combat element (ACE) that will enable the SIF to be maneuverable, lethal, and interconnected with the joint force.

C. MARINE CORPS AVIATION

To create the stand in ACE, the Marines envision modifying the techniques involved in supporting their six major aviation functions. This section discusses these roles and missions and the Marine Corps' concept of Distributed Aviation Operations.

1. Roles and Missions

The Marine Corps Warfighting Publication (MCWP), *Aviation Operations* (2018), states that the role of Marine Corps aviation is to

> provide the Marine Air Ground Task Force (MAGTF) with the operational flexibility it needs to accomplish its mission across the range of military operations. It extends the operational reach of the MAGTF and enables it to accomplish operational objectives designed to achieve strategic goals. (USMC, 2018a, p. 1-1)

The organization, training, and tasks assigned to Marine Corps aviation are designed towards providing a task-organized ACE (USMC, 2018a, p. 2-1). The primary mission of the ACE is to provide support to the MAGTF throughout all phases of expeditionary operations, including sustained operations ashore (USMC, 2018a, p. 2-1).

2. Six Functions

Marine Corps aviation can execute its role and the ACE's mission through six functions: offensive air support (OAS), antiair warfare (AAW), assault support (AS), air reconnaissance (AR), electronic warfare (EW), and control of aircraft and missiles (COAM) (USMC, 2018a, p. 2-1). The missions that make up each function of Marine aviation are depicted in Figure 1.

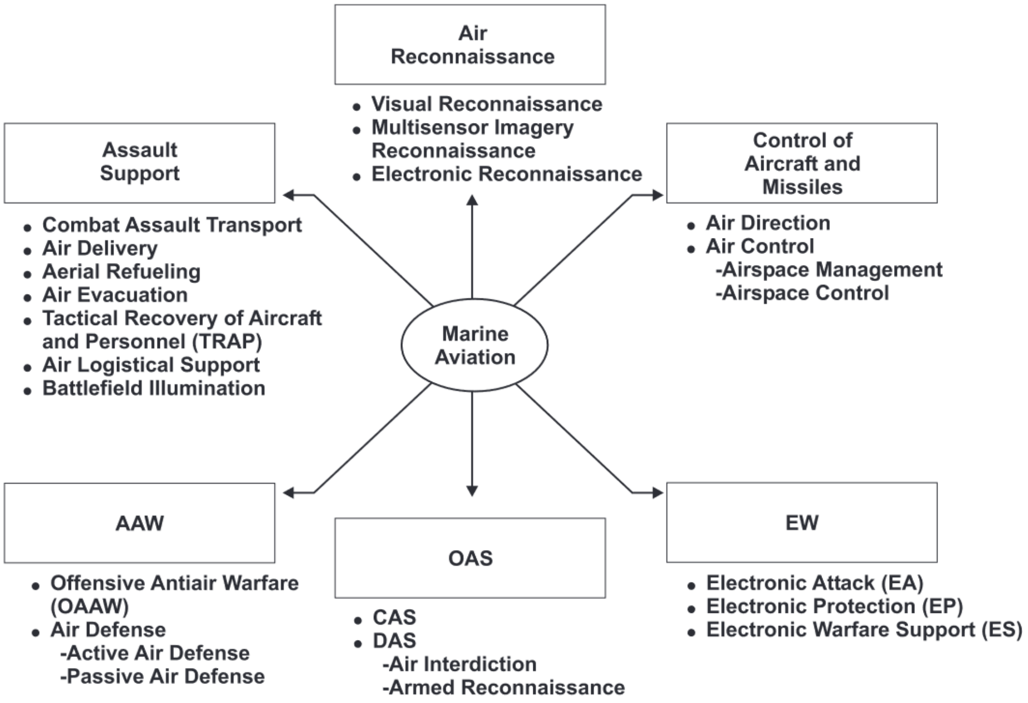


Figure 1. Six functions of Marine Aviation. Source: USMC (2018a).

The six functions of Marine aviation empower the MAGTF commander by delivering capabilities such as “long-range fires (including electronic fires), intelligence collection, enhanced mobility, and force protection” as well as close-range fires to bolster tactical maneuvering (USMC, 2018a, p. 3-1). This tactical aviation support not only enhances the MAGTF commander’s lethality but also provides a broad range of options, showcasing the versatility of actions that the ACE can effectively support. This also highlights that decision-makers have many different choices in their actions.

3. Distributed Aviation Operations

In tandem with the new operational concept of EABO, the entire MAGTF must adapt and change in order to operate in an austere, contested, denied, and degraded environment (Headquarters Marine Corps Aviation [HQMC Aviation], 2023, p. 2). Envisioned in the *TM for EABO*, the role of aviation is to

> leverage the virtues of mass without the vulnerabilities of concentration. Massing distributed effects requires a force that is adept at reconnaissance and counter-reconnaissance, digitally interoperable with the joint force, and physically capable of maneuvering with speed and depth across expansive geographic areas. Marine Corps aviation fills these requirements with critical capabilities that digitally integrate aerial and ground sensing with lethal fires and long-range maneuver and sustainment; enabling the SIF to thrive in a multi-domain contested environment. (USMC, 2023, p. 5-1)

A new concept being explored by Marine Corps aviation is Distributed Aviation Operations (DAO). Stated in Headquarters Marine Corps (HQMC) aviation's report, *Prospectus: Distributed Aviation Operations Functional Concept,* the central idea of DAO is

> to create a lethal, resilient, persistent, and sustainable Aviation Combat Element (ACE) while simultaneously inducing complexity and uncertainty for the enemy through (1) the persistent distribution of aviation elements across extended distances; (2) operation of distributed aviation elements with minimal aviation logistic support from rear-areas; and (3) networking distributed aviation elements with SIF, joint, and coalition command and control systems. (HQMC Aviation, 2023, p. 3)

The central idea of the *Prospectus: DAO* is supported by three additional ideas:

1. Reassessment of Functions of Marine Aviation
2. Hybrid Decision Support Tools (HDST)
3. Contested Logistics Support

This thesis explores HDST and how these tools can enable Marine Corps aviation to succeed in the future fight.

The *Prospectus: DAO* by Headquarters Marine Corps aviation states that HDST focuses on accelerating the decision-making cycle to machine-level speeds with the use of new and emerging technology (HQMC Aviation, 2023, p. 4). HDST is further broken down into six characteristics. As discussed in page 1 of *Prospectus: DAO*, those characteristics are as follows:

1. Decision-Centric approach to military operations
2. Human Command with machine-assisted control
3. Harnessing emerging technologies and concepts
4. Fractionated and heterogeneous force—dynamically composed
5. A means to accelerate capability development and fielding
6. Composable architecture and capabilities

The six characteristics of HDST cover an array of different areas of research, including artificial intelligence, force design, decision-making, and acquisitions. This thesis will focus on the characteristics of a decision-centric approach to military operations and human command with machine-assisted control. Discussed later in this chapter, decision-centric operations are reliant on the ability to think faster than the adversary, gaining a decision advantage, and providing the enemy with a decision dilemma (HQMC Aviation, 2023, p. X1). An identified way to gain a decision advantage is through the use of artificial intelligence and machine learning (HQMC Aviation, 2023, p. X1). Both above mentioned characteristics are inherently connected through the study of decision-making and artificial intelligence.

D. COMMAND AND CONTROL

To better understand decision-making, this thesis explores the basic concepts of command and control (C2), which drives the need for decision-making. This section discusses what is command and control and how the USMC conducts C2 to take effective action during military operations.

1. Definition

Marine Corps Doctrine Publication (MCDP) 6 – Command and Control describes C2 as “the means by which a commander recognizes what needs to be done and sees to it that appropriate actions are taken” (USMC, 2018b, p. 1-4). C2 is an action that occurs before, during, and after the conduct of military operations and is the enabler that allows for all other operations to occur (USMC, 2018b, p. 1-5). *MCDP-6* states that there are two fundamental views of C2. In the first view, the commander has “command” and “control” of his subordinates which results in a top-down unidirectional flow of C2. In the second view, the commander exerts “command” to influence his subordinates, but “control” returns from the commander’s subordinates as a way of feedback to modify command action when needed.

C2 is viewed as a system, where *MCDP-6* identifies the three primary elements as people, information, and a C2 support structure. People are responsible for gathering information, making decisions, implementing actions, engaging in communication, and collaborating to achieve a shared objective (USMC, 2018b, p. 1-15). The second aspect of the C2 pertains to information, which encompasses depictions of reality utilized to inform and provide structure to decisions and actions. Information serves two basic uses. First to help create situational awareness to provide context and meaning for a decision. Second, to provide guidance and direction in the execution of a decision (USMC, 2018b, p. 1-16). Further explanations of information and situation awareness are discussed later in the literature review. The C2 support structure enables the creation, dissemination, and use of information. This element includes the tactics, techniques, and procedures as well as education, training, and equipment that support C2 (USMC, 2018b, p. 1-18).

There are two primary adversaries that may hinder the ability to conduct the goals of C2. Those adversaries are uncertainty and time (USMC, 2018b, p. 1-20). Uncertainty deals with all the unknown factors about a given situation that may prevent a decision-maker from taking action. In the realm of C2, uncertainty is an element of warfare that is constantly evolving and cannot be fully removed, but a goal of the C2 system is to reduce uncertainty enough to allow a decision-maker to take action (USMC, 2018b, p. 1-22). Likewise, time is a constant battle for C2 as it takes time to transform information to knowledge to reduce uncertainty. The knowledge that supports decisions is ultimately perishable. *MCDP-6* summarizes “Command and Control thus becomes a tense race against time. So, the second absolute requirement in any command and control system is to be fast – at least faster than the enemy” (USMC, 2018b, p. 1-23). General George Patton summed this up in World War II with his famous declaration: “A good plan violently executed now is better than a perfect plan executed next week” (USMC, 2018b, p. 3-12).

2. Mission Command and Control

The preferred method of C2 for the Marine Corps is mission command and control. *MCDP-6* states that mission C2 “relies on the use of mission tactics in which seniors assign missions and explain the underlying intent but leave subordinates as free as possible to choose the manner of accomplishment” (USMC, 2018b, p. 3-6). The ability to conduct mission C2 comes from the ability of subordinate commanders to understand commander’s intent, subordinates taking low-level initiative, mutual trust between individuals in the chain of command, and implicit communication between commanders and subordinates (USMC, 2018b, p. 3-7).

For mission C2, decision-making must occur at all levels within the chain of command to support effective operations. Page 3–12 of *MCDP-6* explains the four general principles of military decision-making that all leaders must recognize. The first principle is that the enemy will attempt to impose their will on friendly forces. The second principle is that making decisions faster than the enemy will provide an advantage. The third principle is that decision-making requires intuition and analytical skills to generate creative solutions. The fourth and final principle is that there are no perfect solutions as all decisions are made in an environment of uncertainty.

With a common understanding of the principles of decision-making, mission C2 attempts to address the problems of uncertainty and time to give Marines the winning advantage. *MCDP-6* concludes with the overarching argument for the Marine Corps view on C2:

> Our approach to command and control recognizes and accepts war as a complex, uncertain, disorderly, and time-competitive clash of wills and seeks to provide the commander the best means to win that environment. We seek to exploit trust, cooperation, judgement, focus, and implicit understanding to lessen the effects of the uncertainty and friction that are consequences of war’s nature. We rely on mission command and control to provide the flexibility and responsiveness to deal with uncertainty and to generate the tempo which we recognize is a key element of success in war. We focus on the value and

> timeliness of information, rather than on the amount, and on getting that information to the right people in the right form. We seek to strike a workable balance among people, procedures, and technology, but we recognize that our greatest command and control resource is the common ethos and the results bond shared by all Marines. (USMC, 2018b, pp. 3–32–3-33)

In sum, although war is chaotic and confusing, the side that is able to decide and act more quickly gains the upper hand and achieves victory. However, prior to making a decision, planning must occur.

E. PLANNING

The planning process is a decision-making process. Decisions are made throughout the entire planning process which result in the development of a plan. That developed "plan" supports decision-making for subordinate plans, which drive decision-making during mission execution. Through mission execution, the *plan* is adjusted continuously to adapt. The *plan* feeds briefs for flight planning, end state for unmanned systems, and recommendations given by advanced decision-support agents. This section discusses the concept of planning and the Marine Corps Planning Process (MCPP).

1. Definition of Planning

Marine Corps Doctrine Publication 6 – Command and Control 6 describes planning as a process that:

> Facilitates future decisions and actions by helping commanders provide for those things which are not likely to change or which are fairly predictable (such as geography and certain aspects of supply or transport). Planning helps them to examine their assumptions, to come to a common understanding about the situation and its general direction, to anticipate possible enemy actions, and thus to consider possible counteractions. Planning helps to uncover and clarify potential opportunities and threats and to prepare for opportunities and threats in advance. Conversely, planning helps to avoid preventable mistakes and missed opportunities. (USMC, 2018b, p. 2-22)

Planning is fundamentally a process that is focused on the future and attempts to identify options for the decision-maker (USMC, 2018b, p. 2-23). Depending on time, planning can occur in two ways, rapidly or deliberately (USMC, 2018b, p. 2-23). The primary difference between rapid and deliberate planning is their proximity to execution. For example, the

Marine Expeditionary Unit (MEU) utilizes the Rapid Response Planning Process (R2P2), a modified version of the MCPP to execute a plan within six hours (USMC, 2020, p. 1). However, when execution is not as close, deliberate planning allows commander's and their staffs to develop more detailed and technical plans that include the practical specifics of execution (USMC, 2018b, p. 2-24).

2. Marine Corps Planning Process

MCPP is the primary planning process for Marine units with staffs (USMC, 2020, p. 1). Described in *Marine Corps Warfighting Publication 5-10 – Marine Corps Planning Process*, MCPP consists of six-steps:

1. Problem Framing. Problem framing is the most important step in the planning process and allows the staff to understand the operational environment and ultimately identify what they must accomplish (USMC, 2020, pp. 4).
2. Course of Action (COA) Development. COA development involves creating and evaluating various potential plans to determine the most effective approach for achieving mission objectives (USMC, 2020, pp. 4–5).
3. COA Development War Game. COA war gaming is where potential COAs are simulated and analyzed to assess their feasibility, identify potential challenges, and are refined to achieve mission objectives (USMC, 2020, p. 5).
4. COA Comparison and Decision. Involves evaluating and selecting the most optimal COA from the alternatives considered during the planning process (USMC, 2020, p. 5).
5. Orders Development. "The orders development step translates the commander's decision into oral, written, and graphic direction sufficient to guide subordinate planning, execution, and initiative" (USMC, 2020, p. 5).
6. Transition. The transition phase is where the plan transitions from planning to execution (USMC, 2020, p. 5).

Planning is essential to decision-making. Inherent to developing a good plan is developing situation awareness. Situation awareness is a necessity for the decision-maker as it provides understanding of the operational environment.

F. SITUATION AWARENESS

This section discusses situation awareness (SA) and its relationship with decision-making as well as John Boyd's Observe-Orient-Decide-Act (OODA) loop.

1. Definition of Situation Awareness

Mica Endsley (1995) defined situation awareness as "a state of knowledge, from the processes used to achieve that state […]. It refers to only that portion pertaining to the state of a dynamic environment" (p. 36). As explained by Endsley, situation awareness is then broken down into three hierarchical levels. Level 1 consists of the "perception of the elements in the environment" (Endsley, 1995, p. 36). In an aviation context, this could consist of the air crew observing other aircraft and their characteristics, such as identifying type and model, or recognizing geographical locations (Endsley, 1995, p. 36). Level 2 is stated by Endsley to be "comprehension of the current situation" (Endsley, 1995, p. 37). Level 2 goes beyond mere observation of visible elements, enabling comprehension of the significance of events and objects through cognitive processing (Endsley, 1995, p. 37). Finally, Level 3 consists of "projection of future status" (Endsley, 1995, p. 37). That is, when knowledge about the situation is developed through the observation of elements and comprehension of those elements, the decision maker is than able to project the possible future actions of the observed elements (Endsley, 1995, 37).

2. Model of Situation Awareness in Dynamic Decision Making

The understanding of a situation plays a key role in decision-making. According to Endsley (1995), SA feeds directly into an individual's ability to make decisions. In Endsley's dynamic decision-making model, the cognitive process is composed of a core loop, where the core decision begins with assessing the current state of the environment as made out by the senses of an individual or by the use of a mechanical system such as a sensor (Endsley, 1995, p. 35). The perception of the environment then continues through the process of gaining SA, as discussed in the paragraph above. After becoming familiar with the environment, a decision-maker can proceed to make a decision, which subsequently results in the performance of an action (Endsley, 1995, p. 35). The performance of an action can alter the initial environment, creating a feedback loop that returns to the beginning of the loop. This is the core system of Endsley's dynamic decision-making model.

The core decision-making loop is also affected by individual factors such as goals, memory, information processing mechanisms, experience, ability, and training (Endsley, 1995, pp. 40–49). These individual factors can affect the decision-makers ability to acquire SA and make a decision. External task and system factors also affect SA. These factors are system capability, interface design of the system being used, stress and workload, complexity of the task, and automation of the system (Endsley, 1995, pp. 49–54). Together these individual, task, and system factors contribute to development of SA and the making of decisions in Endsley's (1995) model, which is seen in Figure 2.

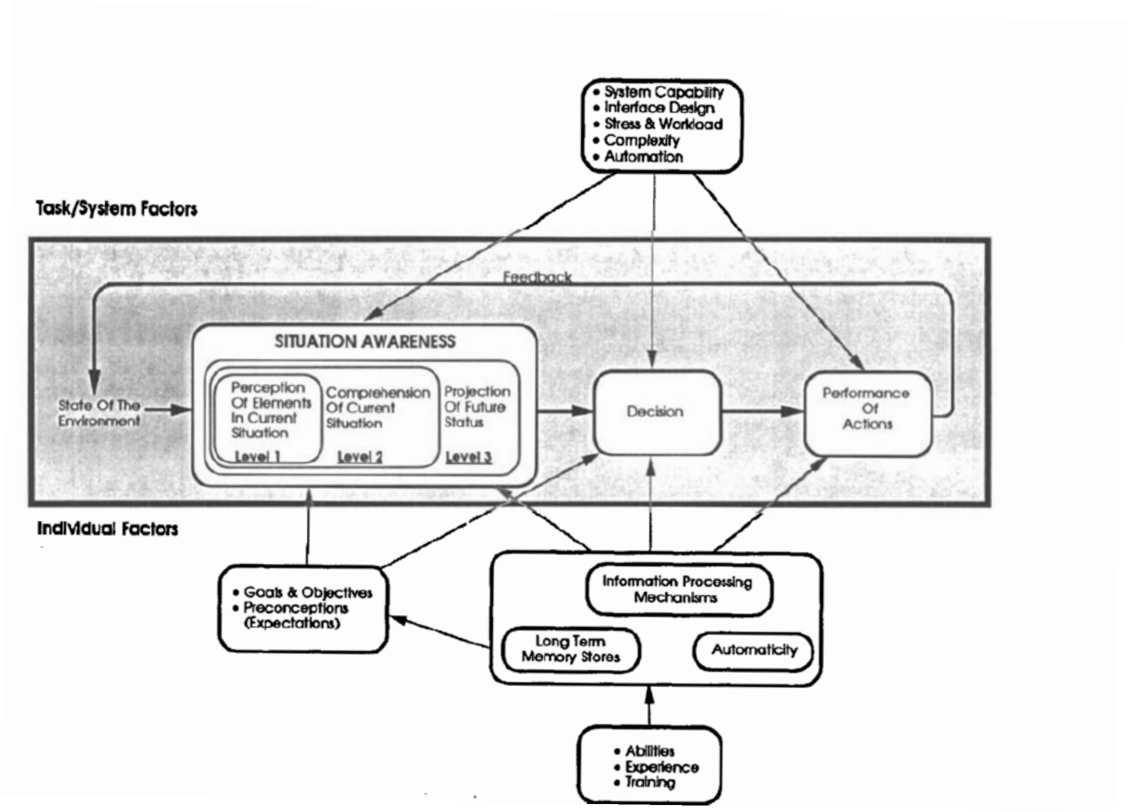


Figure 2. Model of SA. Source: Endsley (1995).

Endsley's model is one example of how context of a situation and the environment affect decision-making.

3. Observation-Orientation-Decision-Action

A popular decision-making model used across the world is John Boyd's Observation, Orientation, Decision, and Action model, known as the OODA loop. Boyd's model first appeared in the 1970s, as a government Air Force brief and was officially published as a book in 1987 entitled *A Discourse on Winning and Losing* (Osinga, 2006, p. 1). Frans Osinga summarized Boyd's core argument as a decision-making cycle "war depends on the ability to out-pace and out-think the opponent, or put differently, on the ability to go through the OODA cycle more rapidly than the opponent" (Osinga, 2006, p. 1). Seen in Figure 3 is the simplest form of the OODA loop according to Osinga. The extended version of John Boyd's OODA loop is presented in Figure 4.

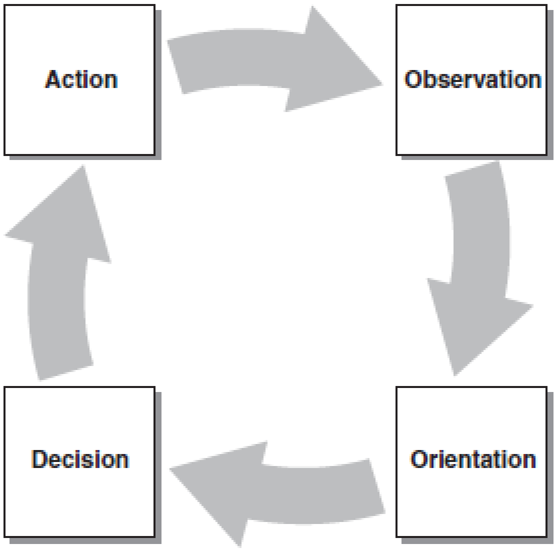


Figure 3. OODA Loop. Source: Osinga (2006).

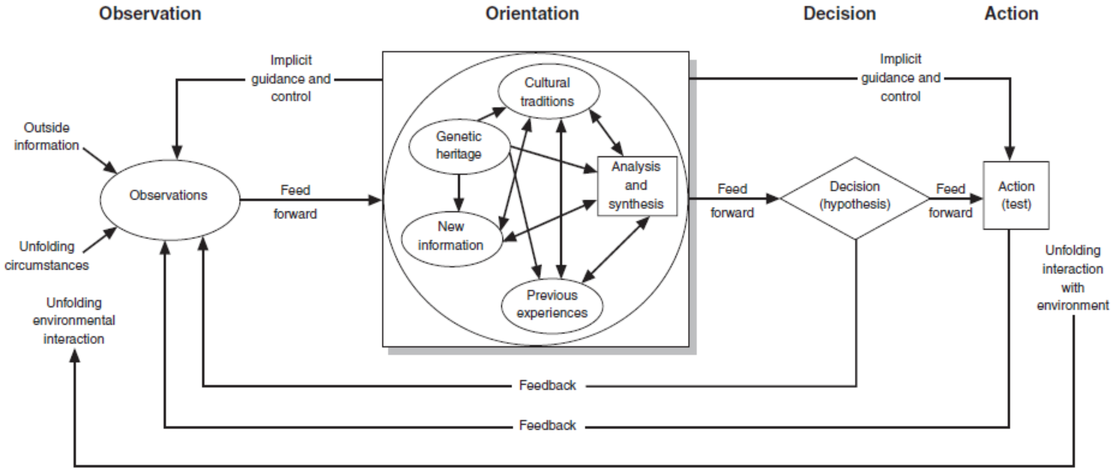


Figure 4. Extended OODA. Source: Osinga (2006).

In Boyd's model, "observation is the task that detects events within an individual's, or group's environment. It is the method by which people identify change, or lack of change, in the world around them" (Osinga, 2006, p. 230). Continuing with the OODA loop, orientation is the method and behavior processes of providing context to what has been observed (Osinga, 2006, p. 230). Similar to Endsley's (1995) dynamic decision-making model, Boyd's observation and orientation phases are related to Endsley's three levels of situation awareness. The decision and action phases of Boyd's model are nearly identical to Endsley's model except for the words used to describe each phase and amount of feedback required. In Boyd's model, feedback to the observation phase occurs at every step of the OODA loop, compared to the single feedback loop in Endsley's model.

A key takeaway from both Endsley's and Boyd's model is the importance of understanding the situation and environment of which the decision-maker is working in. As stated by Osinga, "without the context of orientation, most observations would be meaningless" (Osinga, 2006, p. 230). Just because something can be observed does not always mean it will be useful for the user. Proper development of situation awareness and orientation is what provides context to the decision-maker to create knowledge and ultimately make wise decisions. Orientation, arguably the most time-consuming phase of the decision-making process, presents an opportunity for decision-makers to potentially accelerate their decision-making and gain an advantage by leveraging artificial intelligence.

G. DECISION-CENTRIC WARFARE

The preceding sections identify that EABO necessitates the use of a mission command and control approach that facilitates deciding actions faster than the opponent. There is an implied assumption that not only are the decisions faster, but they are better. This is called Decision-Centric Warfare, and this section discusses what that is. This section uses Mosaic Warfare, a decision-centric approach proposed by the Defense Advanced Research Projects Agency (DARPA), to introduce the ideas.

1. Definition

For the U.S. to regain its military advantage over the adversary, new operational approaches must be experimented with. A decision-centric approach to military operations is a potential solution to gain that advantage. For instance, “instead of attempting to destroy an adversary’s forces until it can no longer fight or succeed, a decision-centric approach to warfare would impose multiple dilemmas on an enemy to prevent it from achieving its objectives” (Clark et al., 2020, para. 3). Decision-centric military operations focus on attacking the adversary’s orientation phase of John Boyd’s OODA loop decision-making cycle (Clark et al., 2020, p. 24). Through the degradation of the adversary’s orientation, U.S. forces develop a decision advantage. With a decision advantage, U.S. forces can increase combat effectiveness through accelerated decision-making. It is expected that decision-centric operations will be assisted through the employment of foundational data precepts, explainable artificial intelligence (AI), user support agents, and human-machine teaming (Clark et al., 2020, p. 23).

2. Mosaic Warfare

Mosaic Warfare is a decision-centric approach proposed by DARPA. Studied by Bryan Clark, Dan Patt, and Harrison Schramm from the Center for Strategic and Budgetary Assessments (CSBA), their findings were published in *Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems to Implement Decision-Centric Operations*. In the CSBA (2020) study, DARPA’s Mosaic Warfare expands on the principles of decision-centric operations by proposing operational changes in U.S. military force design, command and control, force composition, and information exchange (Clark et al., 2020, p. 12). These proposed changes focus on the concept of using single-function distributed forces, which are connected via context-centric command and control kill webs and can be rapidly composed to support the ever-changing operational environment (Clark et al., 2020, p. 12). The approaches to decision-centric military operations and Mosaic Warfare are summarized in Figure 5.

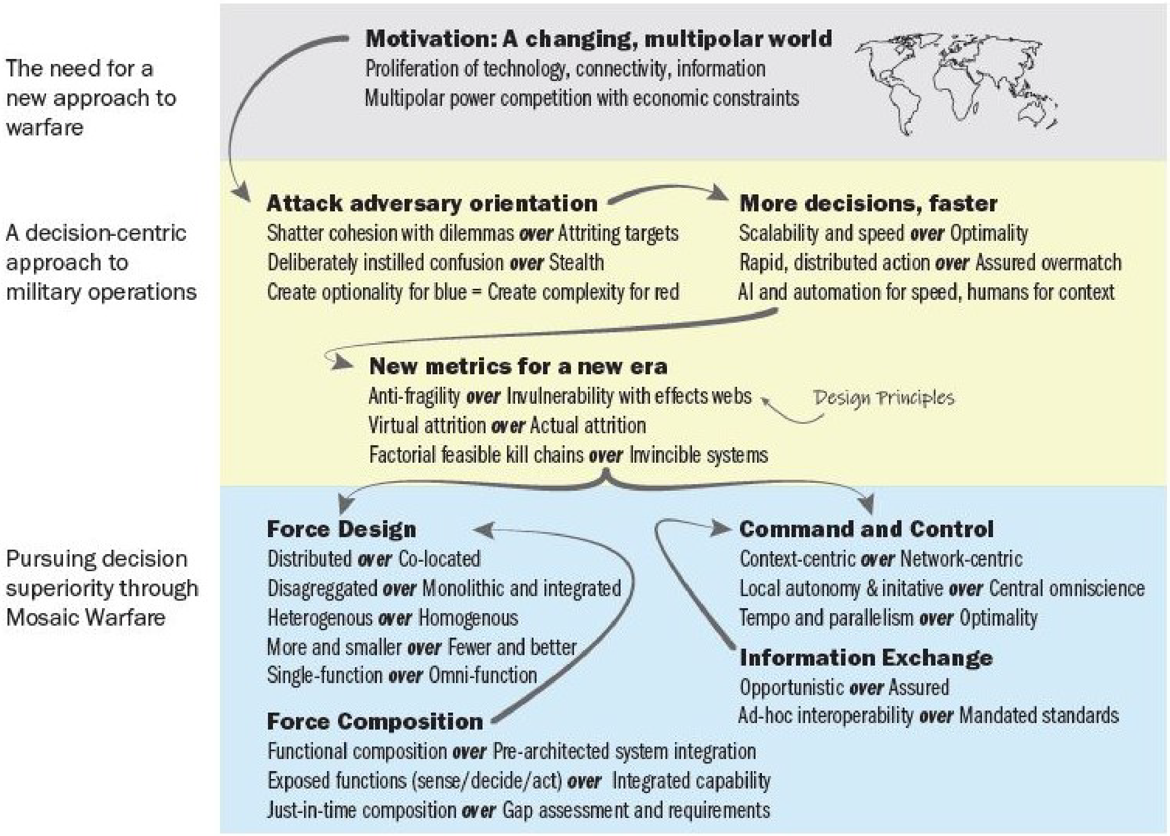


Figure 5. Rationale behind Decision-Centric Warfare. Adapted from Clark et al. (2020).

In the *Mosaic Warfare* study, the concept was tested by the conducting three wargames using the following hypotheses (Clark et al., 2020):

> 1. Commanders and planners can achieve trust in COAs proposed by a machine-enabled control system.
> 2. Mosaic Warfare will increase the complexity of U.S. force packages and degrade adversary decision-making.
> 3. Mosaic Warfare will enable commanders to mount more simultaneous actions, creating additional complexity for adversaries and overwhelming their decision-making.
> 4. Mosaic force design and C2 process will increase the speed of the U.S. force's decision-making, enabling commanders to better employ tempo.
> 5. Mosaic Warfare will better enable U.S. commanders to implement their strategy than operations with a traditional force. (p. 41)

The *Mosaic Warfare* wargames found that the combination of complexity and increased actions in Mosaic forces, had the potential to overpower opponents' decision cycles. The complexity of blue force's actions yielded significant tactical and operational advantages and could be assessed as a deterrence against adversary aggression and prompt them to reassess their actions. However, *Mosaic Warfare* wargames did not explore the impact on adversary commanders due to the absence of a live Red team. The *Mosaic Warfare* study recommended that future wargames investigate the effects of Mosaic Warfare on adversary decision-making and actions, along with considering potential implications of adversaries adopting their own versions of Mosaic Warfare.

An inherent requirement for decision-centric military operations is a distributed web of sensors, decision-makers, and weapons systems that are integrated together seamlessly. The potential size and distribution of manned and unmanned forces reaches levels of complexity that are impossible for human decision-makers to address without assistance. However, before a decision-maker is able to select a course of action with the assistance of an AI supported decision support tool or a missile goes off the rail to engage a target, the entire operational and informational environment will need to apply foundational data principles.

H. DATA FUNDAMENTALS

This section discusses various definitions and concepts of data fundamentals which enable the development of concepts discussed in this thesis. The following are definitions of data fundamental terms.

1. Data. "A collection of discrete or continuous values that convey information, describing the quantity, quality, fact, statistics, other basic units of meaning, or simply sequence of symbols that may be further interpreted formally" ("Data," n.d.).
2. Datasets. "Collections or groups of related data…[that] shares the same set of attributes or properties" (Erl et al., 2016, p. 20).

3. Data Analysis. “The process of examining data to find facts, relationships, patterns, insights and/or trends. The overall goal of data analysis is to support better decision-making” (Erl et al., 2016, p. 21).

Teradata, an American data system corporation, describes Big Data as “a group of data sets too large and complex to manipulate or query with standard tools” (Teradata, n.d.). Teradata additionally describes the five characteristics of Big Data:

1. Volume. “The size and amount of big data that companies manage and analyze.”
2. Value. “The most important “V” from the perspective of the business, the value of big data usually comes from insight discovery and pattern recognition that leads to more effective operations, stronger customer relationships and other clear and quantifiable business benefits.”
3. Variety. “The diversity and range of different data types, including unstructured data, semi-structured data and raw data.”
4. Velocity. “The speed at which companies receive, store and manage data – e.g., the specific number of social media posts or search queries received within a day, hour or other unit of time.”
5. Veracity. “The ‘truth’ or accuracy of data and information assets, which often determines executive-level confidence.”

The Department of Defense (DOD) is an organization that creates an enormous amount of data every day across the various information technology systems, sensors, and weapons platforms in use. Using the above characteristics, it can be clearly seen that the DOD is a Big Data organization, and this is apparent in the DOD’s data strategy.

I. DEPARTMENT OF DEFENSE DATA STRATEGY

This section explores the current DOD data strategy, highlighting its goals of achieving data centricity and gaining a decision-making advantage.

In 2023 the Department of Defense published the *2023 Data, Analytics, and Artificial Intelligence Adoption Strategy* which states:

> The latest advancements in data, analytics, and artificial intelligence (AI) technologies enable leaders to make better decisions faster, from the boardroom to the battlefield. Therefore, accelerating the adoption of these technologies presents an unprecedented opportunity to equip leaders at all levels of the Department with the data they need, and harness the full potential of the decision-making power of our people. (DOD, 2023, p. 3)

This statement reinforces the previous vision statement made in the *2020 DOD Data Strategy* that the DOD must become "a data-centric organization that uses data at speed and scale for operational advantage and increased efficiency" (DOD, 2020, p. 2).

A common theme across the DOD's data strategy is that high quality data is essential to support the creation of decision advantages against an adversary (DOD, 2023, p. 5). On page 5 of the DOD *2023 Data, Analytics, and Artificial Intelligence Adoption Strategy*, a decision advantage is characterized by the following outcomes:

1. Battlespace awareness and understanding
2. Adaptive force planning and application
3. Fast, precise, and resilient kill chains
4. Resilient sustainment support
5. Efficient enterprise business operations

Critical to decision-making and the DOD's vision of being a data-centric organization, is the use of advanced analytics and AI (DOD, 2023, p. 5). The department's strategic goals to support the *2023 Data, Analytics, and Artificial Intelligence Adoption Strategy* follow:

1. Improve foundational data management (DOD, 2023, p. 8).
2. Deliver capabilities for enterprise and joint warfighting impact (DOD, 2023, p. 9).
3. Strengthen governance and remove policy barriers (DOD, 2023, p. 9).
4. Invest in interoperable, federated infrastructure (DOD, 2023, p. 5).
5. Advance the data, analytics, and AI ecosystem (DOD, 2023, p. 5).
6. Expand digital talent management (DOD, 2023, p. 13).

These strategic goals for the 2023 strategy are the enablers of the DOD's AI hierarchy of needs, seen in Figure 6.

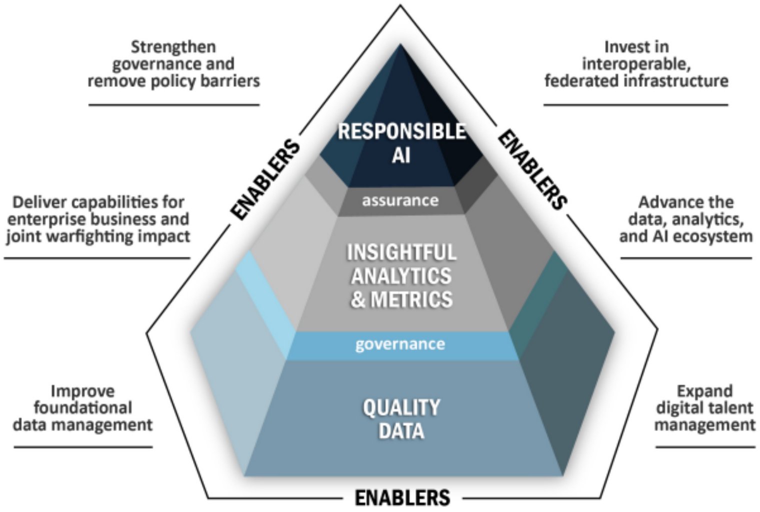


Figure 6. Strategic Goals and the AI Hierarchy of Needs. Source: DOD (2023).

As such, this thesis focuses on the implementation of the strategic goal, foundational data management, as decision-making requires data. This strategic goal plays a fundamental role in the use of artificial intelligence for decision-making support tools and the process of transforming data to information, to knowledge, and ultimately wisdom in support of decision centricity.

J. DATA, INFORMATION, KNOWLEDGE, AND WISDOM (DIKW)

This section delves into the DIKW pyramid, a conceptual model outlining the progression from data to wisdom. This hierarchy, which includes data, information, knowledge, and wisdom, illustrates how each step builds upon the last, adding value and context to the original data. The section also examines how this model, as well as the similar information hierarchy from *MCDP-6*, provides a framework for transforming raw data into meaningful insights that guide decision-making and actions.

1. DIKW

The intent of the DIKW pyramid argued by the digital company Ontotext, is that the pyramid represents:

> Each step up the pyramid answers questions about the initial data and adds value to it. The more questions we answer, the higher we move up the pyramid. In other words, the more we enrich our data with meaning and context, the more knowledge and insights we get out of it. At the top of the pyramid, we have turned the knowledge and insights into a learning experience that guides our actions. (Ontotext, n.d.)

An example of the DIKW pyramid is shown in Figure 7.

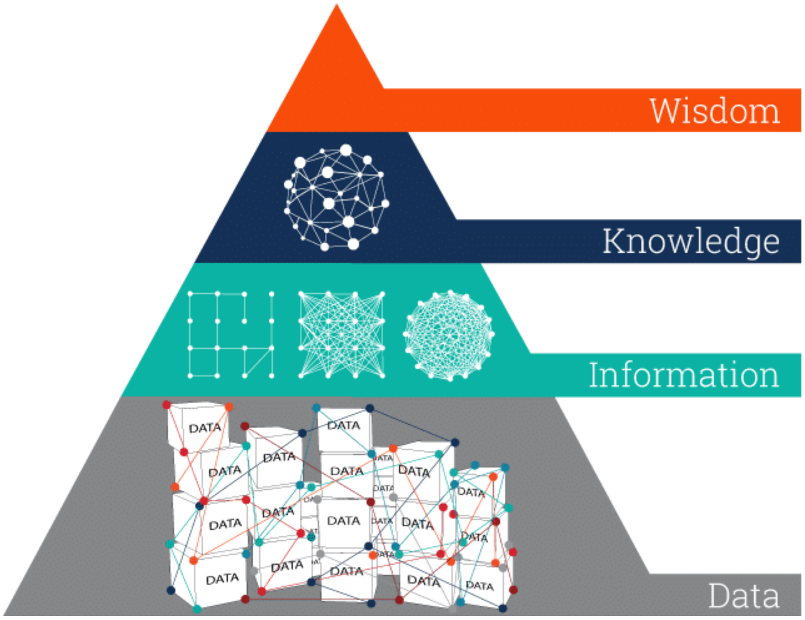


Figure 7. DIKW Pyramid. Source: Ontotext (n.d.).

DIKW represents that there is a fundamental relationship between data and wisdom. That is, as context is applied to the original data its meaning becomes more valuable to the user. *MCDP-6* emphasizes this relationship at a higher conceptual level.

2. Information Hierarchy

Marine Corps Doctrine Publication – 6 Command and Control uses a similar model of the information hierarchy by Jeffrey R. Cooper to represent the relationships of raw data after it has been processed, and how it becomes knowledge once it has been analyzed. The ultimate goal is for the data to lead to a greater understanding of the situation. Figure 8 explains the hierarchical relations in converting data to synthesized and visualized understanding.

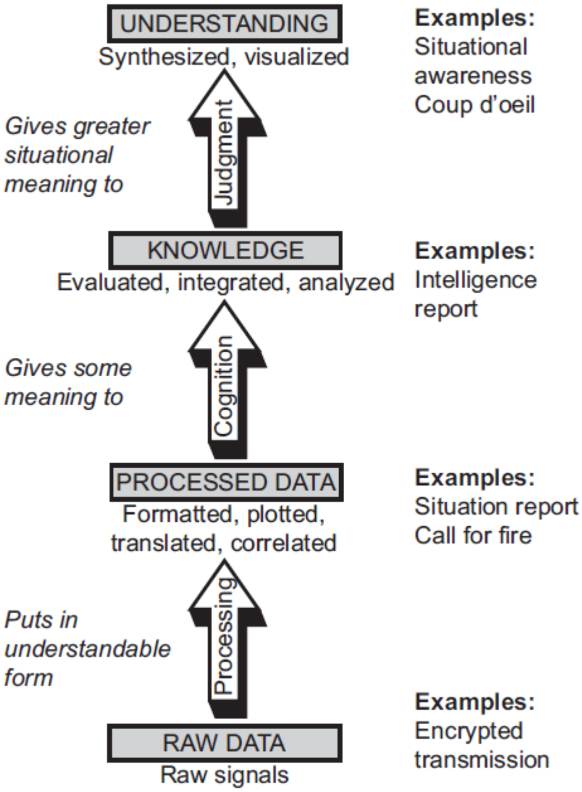


Figure 8. Information Hierarchy. Source: USMC (2018b).

The general concepts of the DIKW pyramid and information hierarchy are very similar and primarily differ with the use of the word "information." *MCDP-6* uses the word "information" to describe the four classes: raw data, processed data, knowledge, and understanding, while DIKW has information as its own class. Although information is used differently, both models strive to convey that when data or information is given context and meaning, it becomes more valuable, thus allowing for understanding, leading the decision-maker to make a decision and take action.

3. Data/Raw Data

At the bottom of both models is data. Ontotext simplifies data as "a collection of facts in raw or unorganized form such as numbers or characters" (Ontotext, n.d.). Raw data provides the fundamental building block of the DIKW pyramid. To progress to the next step in both models, data must be processed. *MCDP-6* describes processing as "formatting, translating, collating, plotting … processing occurs automatically (whether by humans or by machines) without us even being aware that it is taking place—such as when a facsimile machine converts bits of data into understandable text" (USMC, 2018b, p. 2-9). Once processed and given context, data can be understood as information.

4. Information/Processed Data

Initiating the process of extracting information from data involves posing fundamental questions, such as who, what, when, and where. These questions serve to establish the data's relevance to the user. When data is given context, it is transformed into information and moves up along the DIKW pyramid. Ontotext continues to explain that information consists of data "that has been 'cleaned' of errors and further processed in a way that makes it easier to measure, visualize and analyze for a specific purpose" (Ontotext, n.d.). When cognitive processes are applied to information, knowledge is gained, progressing the original data up along the DIKW pyramid and the user starts to learn what something means (USMC, 2018b, p. 2-9).

5. Knowledge

MCDP-6 describes "knowledge as data that have been analyzed to provide meaning and value" (USMC, 2018b, p. 2-7). Ontotext further describes the acquisition of knowledge from information as "how pieces of information connected to other pieces help us understand how to apply information to achieve our goal" (Ontotext, n.d.). Information must be given meaning to be applicable to the user. The user gives meaning to the information they receive by relating information to the goals and mission of the user through the use of cognition (USMC, 2018b, p. 2-9). Knowledge is then gained through the application of cognition. The results of the knowledge can be represented as solutions to a problem or projections on future events to come. Once knowledge is obtained, the skill of judgment, the utilization of prior experience, knowledge, and intuition can lead to the development of wisdom for the user.

6. Wisdom/Understanding

Wisdom is the final portion of the DIKW pyramid. Described by Ontotext, wisdom within the context of the DIKW pyramid is the application of knowledge in order to take action. The application of knowledge answers the questions, "why do something" and "what is best" (Ontotext, n.d.). *MCDP-6* summarizes that once understanding is attained, a decision-maker has a deeper level of awareness for the events unfolding around a situation, allowing them to make a decision. The obtainment of wisdom and understanding ultimately allows the decision-maker to take action.

7. Context

Fundamental to the transformation of data to wisdom involves adding context to data and information. In the article *Towards a Better Understanding of Context and Context-Awareness*, context is defined as:

> Any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. (Abowd et al., 1999, p. 11)

Extending the idea of context, in the 2019 article *Context-Driven Proactive Decision Support for Hybrid Teams*, context awareness is explained as the capacity of a system to deliver pertinent information or services to users by employing contextual information, with the relevance determined by the user's specific task (Manisha et al., 2019, p. 44). Context and context awareness also play a crucial role in the area of human-machine teams, which will be discussed later in the literature review.

The DIKW pyramid and information hierarchy are tools to understand the transformation of data to wisdom and understanding through the use of processing, cognition, and judgement. These models are not just limited to human processes for the transformation of data. Artificial intelligence and machines are capable of processing data at high speeds to create information and utilize algorithms to analyze information to present projections and potential solutions for human decision-makers.

K. ARTIFICIAL INTELLIGENCE

This section discusses what is artificial intelligence, the four components that make up AI, machine learning, and uses for artificial intelligence to support decision-making.

1. Definition

In John McCarthy's article *What is Artificial Intelligence?* AI is described as

> the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable. (McCarthy, 2007, p. 2)

To further explain artificial intelligence, Rafay Chaudhary (2019) explains the Turing test in his article, *Artificial Intelligence: More than Machine Learning*. Chaudhary asserts that the Turing test evaluates a machine's ability to show behavior that could be deemed intelligent or undiscernible from a human. When conducting the Turing test, a human questioner asks both a machine and a human respondent a number of questions and will receive answers back in response. If the human questioner cannot determine whether the respondent is a human or machine, the claim could be made that the machine is *intelligent* (Chaudhary, 2019, pp. 1–2).

2. Components

AI can be broken up into four separate components: reasoning, natural language processing (NLP), planning, and machine learning (ML) (Chaudhary, 2019, p. 4):

1. Reasoning. Reasoning is described by Chaudhary as "the machine making inference using data" (Chaudhary, 2019, p. 2).
2. Natural Language Processing. "This is giving the computer the ability to read and understand human languages. However, it requires a myriad of technologies such as dictionaries, ontologies, language models, etc." (Chaudhary, 2019, p. 2).

3. Planning. “If someone is deemed intelligent, they must be able to set goals and accomplish them… The computer must have the ability to act autonomously and flexibly to construct a sequence of actions to reach a final goal” (Chaudhary, 2019, p. 3).
4. Machine Learning. “Algorithms that improve automatically through experience” (Chaudhary, 2019, p. 3).

3. Machine Learning

Machine learning itself can be broken down into subcomponents. Those subcomponents are unsupervised learning, supervised learning, reinforcement learning, and deep learning (Chaudhary, 2019, pp. 3–4):

1. Unsupervised learning. This type of learning is when a machine processes raw data and categorizes that data using patterns implemented through algorithms. (Chaudhary, 2019, p. 3).
2. Supervised learning. Supervised learning involves utilizing pre-existing knowledge, typically in the form of a dataset containing historical data, to train a machine. Through this training process, the machine learns patterns from the provided data, enabling it to make predictions for upcoming data points or sets in the future. In essence, the machine leverages past data to identify patterns and draw inferences for future data (Chaudhary, 2019, p. 3).
3. Reinforced learning. For reinforced learning, the machine learns not from a fixed dataset but through a process of trial and error. This approach is commonly employed in robot and game development, where the machine learns from successive attempts, reinforcing actions that lead to successful outcomes (Chaudhary, 2019, p. 4).
4. Deep Learning. Deep Learning, the last form of ML, employs neural networks reminiscent of the human brain. It excels at discerning patterns in unstructured data, as opposed to more basic algorithmic methods. (Chaudhary, 2019, p. 4).

4. Artificial Intelligence in Decision Support

Within the realm of decision-making, there are many applications that AI can assist with. However, before discussing the applications an explanation of benefits and challenges must be examined in the role of AI in decision-making.

Argued by the technology company, Upwork, the importance of AI can be realized in decision-making through the following applications:

1. Predictive analytics
2. Risk assessment and mitigation
3. Natural language processing
4. Recommender systems
5. Optimization and resource allocation
6. Fraud detection and prevention
7. Cognitive decision making

Through the use of these applications, effects such as enhanced accuracy of data analysis, faster decision-making, improved efficiency for repetitive tasks, better risk assessment, and data-drive insights correlated through pattern recognition can be achieved through the use of AI (Upwork, n.d.). While these are capabilities identified by a commercial company, agencies such as DARPA and the U.S. military services have been developing advanced planning systems for decades as well, which will also support decision-centric operations.

However, as with any technology there are barriers and risks to use, and this is no different with the application of AI and ML in decision-making. Upwork describes these challenges below:

1. Data quality and reliability. AI is dependent on data to conduct decision making. If given inaccurate data, AI decision-making may be flawed.
2. Lack of human understanding and context. AI is unable to apply human understanding to interpret context that is not present in its model or algorithms.

3. Ethical considerations. Potential ethical concern could arise related to AI use when associated with privacy, fairness, transparency, and accountability.
4. Interpretability and explainability. Decisions made by complex algorithms and AI models may be difficult to explain to human users and strain trust in AI. If a human cannot understand why an AI decision support tool came to a specific conclusion, the human may be hesitant to accept the AI's prediction.
5. Overreliance and decision bias. AI is a tool and human oversight is still required. Blindly relying on AI may produce overreliance and introduce biases.
6. Developing unwarranted trust. Related to overreliance, humans must be wary of unwarranted trust in AI. Humans must not mistake complex AI predictions for human intellect.

In conclusion, artificial intelligence plays a significant role in supporting decision-making, offering a variety of applications such as predictive analytics, risk assessment, and cognitive decision-making. However, the integration of AI into decision-making processes also presents challenges, including data quality, ethical considerations, and the potential for overreliance. By addressing these challenges and leveraging AI's strengths, the Marine Corps can harness its potential to enhance decision-making accuracy, speed, and efficiency, ultimately transforming the way decisions are made across various domains.

L. HUMAN-MACHINE TEAMING

This section discusses the concepts of human-machine teaming (HMT); interdependence; and observability, predictability, and directability (OPD).

1. Definition

A human-machine team can be described as a collection of humans and machines or autonomous agents that work together for a joint purpose (Greenberg & Marble, 2023). In this section, the term machine will be synonymous with the terms robots, unmanned systems, and *intelligent* or collaborative agents.

2. Interdependence

HMT is reliant on a relationship between a human and machine to carry out and perform a task. This overarching relationship is called interdependence. Defined in the article *Coactive Design: Designing Support for Interdependence in Joint Activity*, interdependence is described as “the set of complementary relationships that two or more parties rely on to manage required (hard) or opportunistic (soft) dependencies in joint activity” (Johnson et al., 2014, p. 5). The dependencies in a relationship are further able to be measured through the resources and abilities of an agent to perform a task (Johnson et al., 2014, p. 5). This is called capacity. When an agent has the capacity to complete a given task, it is considered independent. If the agent does not have all required capacity to complete a task, it is considered to have a dependence (Johnson et al., 2014, p. 5).

Described in the definition of interdependence are the terms of required and opportunistic dependencies within a joint activity. A required (hard) dependency, for example, would be the movement of cargo by tractor trailer. The tractor trailer does not have the capacity to move itself and is dependent on a semi-truck for movement. However, a semi-truck does not have the capacity to carry cargo itself and is dependent on the tractor trailer to complete the joint task. An opportunistic (soft) dependency for example would be two friends moving household goods from one location to another. If both friends decide to use their vehicles to move the goods instead of just one, they enhance their team performance by taking fewer trips. These two examples show the complementary relationships found within interdependence to support joint activities (Johnson et al., 2014, pp. 5–6).

3. Observability, Predictability, and Directability

Described in *Coactive Design: Designing Support for Interdependence in Joint Activity*, OPD terms are defined below:

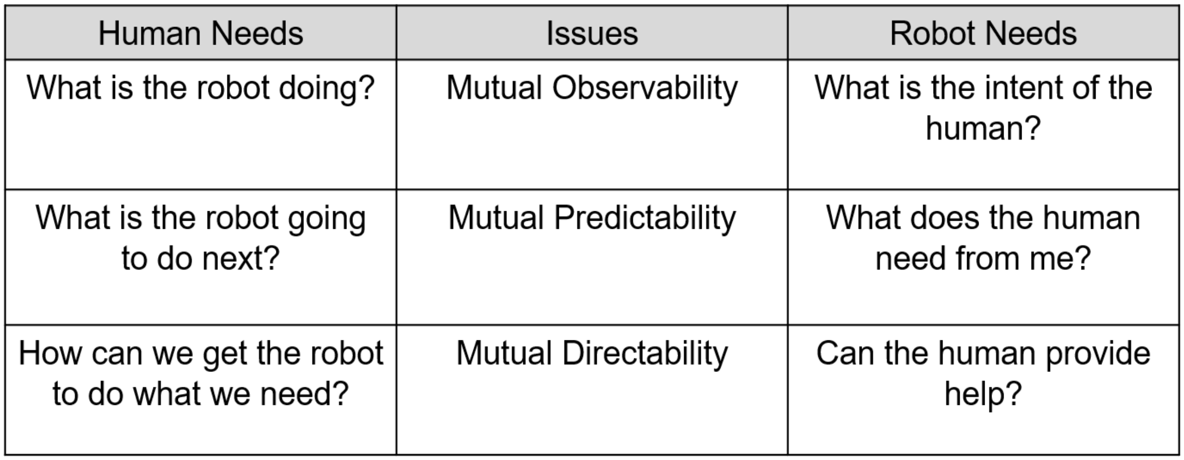
1. Observability. “Making pertinent aspects of one’s status, as well as one’s knowledge of the team, task, and environment observable to others. Since interdependence is about complementary relations, observability also

involves the ability to observe and interpret pertinent signals" (Johnson et al., 2014, p. 9).

2. Predictability. "Means one's actions should be predictable enough that others can reasonably rely on them when considering their own actions" (Johnson et al., 2014, p. 10).

3. Directability. "Means one's ability to direct the behavior of others and complementarily be directed by others…includes explicit commands such as task allocation and role assignment as well as subtler influences, such as providing guidance or suggestions or even…information that is anticipated to alter behavior." (Johnson et al., 2014, p. 10).

As an example, in Figure 9, OPD is shown in the context of needs required by a human-robot relationship:



Human Needs	Issues	Robot Needs
What is the robot doing?	Mutual Observability	What is the intent of the human?
What is the robot going to do next?	Mutual Predictability	What does the human need from me?
How can we get the robot to do what we need?	Mutual Directability	Can the human provide help?

Figure 9. Human-Robot Relationship. Source: Johnson (2016).

In a 2021 study conducted by the Massachusetts Institute of Technology (MIT), *Evaluation of Human-AI Teams for Learned and Rule-Based Agents in Hanabi*, showed the importance of OPD in the context of human-machine teams playing the board game *Hanabi*. In this study, a rule-based AI and a reinforced learning AI human-machine team were compared and evaluated on the metric of team performance in *Hanabi*. Secondary metrics of teamwork, trust, and preference of the AI teammates were also assessed. What was found in MIT's 2021 study was that although scores between teams of various AI models were similar, human participants generally did not trust or prefer to work with a reinforced learning AI as that agent's actions were more difficult to predict compared to a rule-based AI (Ho et al., 2021, p. 2). It was concluded in the study, that even though reinforced learning AI agents have shown superior performance in many areas of AI application, reinforced learning AI did not prove to humans to be a good teammate. Additionally, the MIT study concluded that human perception of AI in design and development must be a key consideration for AI application in the future (Ho et al., 2021, p. 10).

The design principles of OPD are important in the implementation of human-machine teams as they allow for the development of relationships between teams.

M. WORKFLOW

This section explores the concepts of workflows and adaptive workflows, delving into their definitions and roles in decision-making processes. The section also examines causality and non-monotonic reasoning, which are essential for understanding how workflows can be adapted to dynamic environments. These concepts lay the groundwork for utilizing machine learning and AI in workflow management and decision-making.

1. Definition

As defined by the Merriam-Webster dictionary, a workflow is a "sequence of steps involved in moving from the beginning to the end of a work process" (Merriam-Webster, n.d.). As stated by Arkady Godin in his technical report *Contextual Situation-Aware Workflow Architectures at the Tactical Edge*, workflows are designed for repeatable processes and are dependent on content and context to function (Godin, 2023, p. 3).

2. Contextual Situation-Aware Workflow

In traditional business practices, workflows are designed as static; however, for military operations, workflows must be adaptive and situationally aware (Godin, 2023, p. 4). Due to the uncertainty of warfare and the difficulties humans face when handling multiple situations simultaneously, machine digital workflows could assist in managing and exploiting large amounts of data (Godin, 2023, p. 4). Godin argues that a "digital brain" or artificial intelligence agent directly connected to sensors could potentially observe the emergence of events in the environment more quickly than a human cognitive brain that must statically generate knowledge from the data and information presented (Godin, 2023, p. 5). However, a digital brain must have the correct mental model and appropriate context, as discussed in previous sections, to develop correct knowledge to support a decision-maker. Godin expresses that a machine with non-monotonic causal logic could allow for the correct understanding in a multi-dimensional context (Godin, 2023, p. 5).

3. Non-Monotonic Causal Logic

Causal reasoning is a natural method of human thought. In simplest terms, causal reasoning is the idea of cause and effect. Described by Pier Ippolito (2021), causality asks question such as "what if I take this action? What if I would have acted differently?" (Ippolito, 2021). An example of causal reasoning is an individual tending to two plants. In this scenario, the person decides to water only one of the two plants. Upon observation, the individual notes that the watered plant exhibits more significant growth compared to the non-watered one. Consequently, the individual deduces that the act of watering, which is viewed as an intervention, directly contributes to the increased size of plants. Cause and effect. Causal reasoning can be divided into three hierarchical levels:

1. Association. Refers to the relationship observed between two variables. Association signified that changes in one variable are related to changes in another. However, association (aka correlation) does not alone imply causation (Bachman et al., 2018, p. 123).
2. Intervention. Involves studying the impact of deliberately manipulating one variable to observe the effect on another variable (Bachman et al., 2018, p. 127).
3. Counterfactuals. Counterfactuals involve reasoning about what would have happened if a certain event or intervention had not occurred. It compares the

> actual outcome with what might have happened under different condition (Bachman et al., 2018, p. 120).

Non-monotonic logic (NML) is the logical system where conclusions are drawn tentatively by reasoners, with the flexibility to revise or retract them based on additional information (Strasser & Antonelli, 2019). A common example in the literature for NML is Tweety Bird. When presented with a bird named Tweety, the reasoner infers that Tweety must fly on the basis of the information that Tweety is a bird, and birds can fly. However, if given the information that Tweety is a penguin, the reasoners can retract their previous conclusion and make a new conclusion that Tweety cannot fly, or at least not in the air (Strasser & Antonelli, 2019).

When combining these two logics, the idea of non-monotonic causal logic is formed. When applied to AI, causality provides explainability for AI-made decisions and NML provides adaptability for AI decisions to cumulative updates based off of new information received. What makes non-monotonic causal logic important for military decision-making is its potential ability to adapt to the uncertainty of war and associate relationships with cause and effect. Explained by Ryuta Yoshimatsu (2023) in regard to the application of causal machine learning:

> Decision making depends on understanding the effects of decisions on the outcome. If we want to optimize how we make decisions, we need to think about causality. The predictions from machine learning are not enough because our decisions and actions can change the associative patterns that machine learning depends on. Causal inference addresses this challenge directly, but it does run into new challenges. Firstly, we have to start bringing in external knowledge and augmenting our observational dataset. Secondly, we need new methods to estimate the counterfactuals and we need new methods to validate those estimates. (Yoshimatsu, 2023, para. 13)

No method of logic for AI is perfect for decision-making, however causal reasoning has shown to be beneficial as a method for AI to make sense of information in a dynamic environment that goes beyond basic pattern recognition and prediction. With the desire to achieve a decision advantage and develop dynamic workflows by leveraging AI and automation, further research and development in causal inference and non-monotonic causal logic should be conducted (Godin, 2023, p. 20).

N. CONCLUSION

In summary, this chapter has provided a comprehensive overview of the foundational elements essential for Decision-Centric Aviation Operations, including Marine Corps aviation concepts, artificial intelligence, machine learning, data fundamentals, and the transformation from data to wisdom. These concepts underscore the importance of situational awareness, adaptive situation- and concept-aware workflows, and human-machine teaming in achieving a decision advantage. The insights gained from this chapter set the stage for exploring the research methodology, which will delve deeper into the practical applications and strategies needed to implement decision-centric operations effectively.

III. RESEARCH METHODOLOGY

A. APPROACH

This research adopts a qualitative analysis approach, structured around a three-step methodology. The first step involves a thorough review of existing publications and literature. Following this, the second step includes direct engagement with the academic community through visits and participation in workshops at the University of Connecticut and Massachusetts Institute of Technology’s Lincoln Labs. The final step utilizes diverse analytical tools and frameworks to deepen the investigation by use of vignettes to explore complex scenarios relevant to decision-making. In addition to these academic interactions, discussions with the Cunningham Group at Headquarters Marine Corps Aviation were instrumental in defining the scope of the research problem posed by the topic sponsor.

B. RESEARCH PURPOSE

A central theme of this thesis is to explore how Decision-Centric Aviation Operations can lead to decision advantages. After a comprehensive review of literature, engaging with academia, and consultations with the topic sponsor, this analysis identifies two primary components of decision advantage: (1) the ability to make decisions more swiftly than the adversary, and (2) ensuring that decisions deliver value in their respective contexts. The concept of placing the enemy in a decision dilemma is not a new idea as Marines have utilized the concepts of maneuver warfare and combined arms to place the enemy at a disadvantage. Looking ahead, the evolving landscape of warfare is expected to integrate artificial intelligence, automation, and sophisticated decision support tools to further expedite decision processes (HQMC Aviation, 2023, pp. 1–2). Consequently, this thesis examines Marine Corps aviation planning and operations, aiming to enhance decision-making efficiency for DCAO.

C. METHODOLOGY

In Chapter IV, the methodology for analyzing decision-making in Marine Corps aviation planning and operations is presented through the development of two detailed vignettes. These vignettes illustrate decision-making processes across varying time scales—from days and hours to mere minutes and seconds. Each vignette is explored in two scenarios: one assessing the implications of current capabilities and the other considering future advancements in aviation capabilities. The analysis focuses on key themes such as data and information flow, decision metrics, time constraints, uncertainty, and the potential integration of AI agents. Through this exploration, decision dilemmas associated with emerging technologies and new practices will be discussed and improvement adjustments identified.

The first vignette utilizes the Aviation Planning Actions process found in *Marine Corps Warfighting Publication (MCWP) 5.11.1 – Aviation Planning* as the backdrop to analyze decision-making during planning. This process is found specifically in the "MAGTF Aviation Planning for Amphibious Expeditionary Operations" chapter of *MCWP 5.11.1* (USMC, 2002, p. 2-1). Although this process is described within the context of amphibious operations, it is equally applicable to aviation operations supporting littoral forces involved in EABO. The Aviation Planning Actions process fuses into the Marine Corps Planning Process, integrating aviation planning actions to facilitate aviation support to MAGTF planning and operations. Figure 10, from *MCWP 3-25.5 – Marine Tactical Air Command Center Handbook*, shows the aviation planning products generated from the Aviation Planning Actions process as it is integrated into the MCPP.

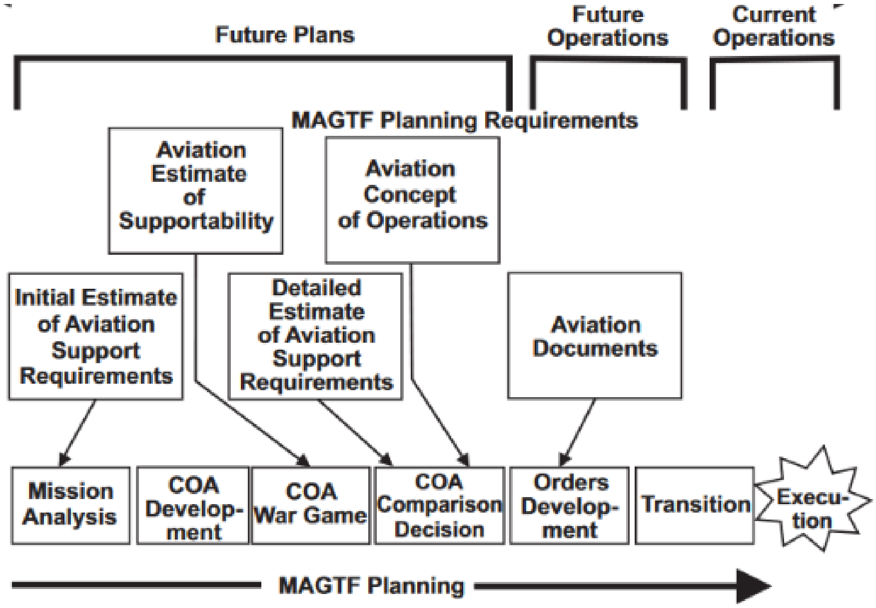


Figure 10. Aviation Panning Products. Source USMC (2018c).

The Aviation Planning Actions process focuses on planning and decisions made prior to execution of a plan. This thesis will also investigate decision-making processes involved during execution of an operation. Vignette 2 is a continuation of vignette 1 but takes place during the execution of vignette 1's plan.

The analysis concludes by extracting common concepts and ideas across the vignettes, utilizing the data, information, knowledge, understanding (DIKU) hierarchy. This approach allows this study to map out the flow of data and information, identify processes that enhance the value of data or information, and pinpoint where context is integrated to elevate understanding. By applying the DIKU hierarchy, this study not only clarifies how information is transformed into actionable insights, but also highlights potential areas for improvement in decision-making processes.

D. CHAPTER SUMMARY

This chapter has outlined the methodology employed to analyze and create a decision advantage for the Decision-Centric Aviation Operations. By examining the planning and decision-making frameworks utilized within Marine aviation, this research will develop detailed vignettes in the subsequent chapter. These vignettes will not only illustrate the relative strengths and weaknesses of current and emerging data science technologies in the decision-making process but will also offer critical insights into the development of DCAO capabilities. Ultimately, this approach aims to highlight practical applications and benefits, thereby contributing to the enhancement of decision-making in Marine aviation.

IV. RESULTS OF ANALYSIS

A. CHAPTER OVERVIEW

This chapter presents an analysis of decision-making within the realm of Marine Corps aviation, focusing on the development of Decision-Centric Aviation Operations. To facilitate this exploration, two detailed vignettes are presented, each examining decision-making processes over different time epochs—from days and hours to mere minutes and seconds. The complete texts of these vignettes are included as appendices to this thesis. Structured in three parts, the chapter begins with a description of the first vignette, which revolves around planning for an aviation operation within an EABO scenario and the subsequent decision dilemmas encountered in the vignette. The following section mirrors this structure but shifts focus to tactical decision-making in an aircraft cockpit. Both vignettes are examined in two iterations, analyzing the implications of both current and future aviation capabilities. The concluding part of the chapter discusses the main findings obtained in the vignettes by applying the DIKU framework (data, information, knowledge, understanding) and illustrating how improving this framework enhances operational decision-making knowledge.

B. DESCRIPTION–VIGNETTE 1

Vignette 1 is a scenario where Marine Corps forces are conducting EABO in the competition phase of conflict (see Appendix A). In the vignette, war has not broken out between the United States and the People's Republic of China (PRC), however the massing of Chinese forces in the vicinity of Taiwan has sparked the movement of USMC equipment within the Luzon Strait of the Philippines. The unit conducting EABO is the 3rd Marine Littoral Regiment (MLR) with an attached Marine Aircraft Group (MAG) composed of three rotary wing squadrons. The vignette follows the planning efforts of the MAG as they are tasked with supporting assault support of Marines and equipment to a new expeditionary advanced base (EAB) location as well as the escort of two Light Amphibious Warships (LAW). Vignette 1 describes the aviation planning process taken by the MAG to support the MLR's maneuver. Vignette 1 is evaluated through three themes: time, planning thoroughness, and explainability.

C. ANALYSIS–VIGNETTE 1

This section discusses the themes involved in vignette 1, which include time, planning thoroughness and the explainability of the action taken. It then examines the decision dilemmas the planners encountered in the modern-day scenario presented, and the changes DCAO methods provide to solve such decision dilemmas.

1. Themes

a. Time

Time serves as a critical metric in evaluating decision-making processes and outcomes for several reasons. As stated in *Marine Corps Doctrine Publication 6 – Command and Control*, effective command and control allows for quicker decision-making and increased tempo which is invaluable in fast-paced environments where opportunities are fleeting (USMC, 2018b, p. 3-3). Conversely, more time available for deliberate planning may result in thoroughness and additional risk assessment, which can reduce uncertainty for operations (USMC, 2018, p. 1-23). By examining the timelines associated with decision-making and its consequences, Marines can gauge the quality, appropriateness, and impact of those decisions. In Table 1 are measures of effectiveness and performance used to evaluate this theme.

Table 1. Measures of Effectiveness/Measures of Performance Associated with Time

Measures of Effectiveness/Measures of Performance associated with Time	
Decision Time	The measurement of the average time taken from recognizing the need for a decision to actually making the decision.
Timely Execution	The measurement of how decisions are implemented and how quickly they are translated into action.
Decision-Making Speed vs. Quality	A ratio comparing the time taken to make a decision against the measured quality of the decision.

b. Planning Thoroughness

Thoroughness of planning depends on available time. While conducting MCPP, the thoroughness of planning serves as an indispensable metric for evaluating strategic effectiveness and operational readiness. A well-developed plan, characterized by comprehensive intelligence analysis, detailed branches and sequels, and robust logistical support, can reflect a high degree of preparedness and adaptability. As stated in *MCDP-6*, "a thorough, deliberate planning effort in advance of a crisis can provide the situational awareness that allows a commander to exercise effective intuitive decision-making" (USMC, 2018b, p. 2-40). Thorough planning is crucial in ensuring that military operations can withstand the unpredictable aspects of warfare, where unforeseen challenges and adversaries' counteractions demand rapid adaptation and flexibility. Moreover, the depth and breadth of planning indicate Marines' ability to wargame potential scenarios, effectively allocate resources, and coordinate actions across the operational environment. In Table 2 are measures of effectiveness and performance used to evaluate this theme.

Table 2. Measures of Effectiveness/Measures of Performance Associated with Planning Thoroughness

Measures of Effectiveness/Measures of Performance associated with Planning Thoroughness	
Number of Courses of Action (COA) developed	The number of COAs considered in the planning process. This measure evaluates the thoroughness of planning by assessing the variety of potential strategies explored.
Number of Comparison Metrics Determined	The number of metrics identified for comparing COAs. This measure assesses how well the planning process incorporates tools for evaluating and differentiating between strategies.
Number of Key Points/Actions Identified	The number of essential actions or milestones outlined for the selected COA. This measure evaluates the thoroughness with which key steps are identified, contributing to effective execution.
Identification of Most Dangerous/Likely Enemy COAs	The extent to which potential enemy COAs or actions are identified and accounted for. This measure evaluates the planning process's capacity to anticipate and mitigate possible threats.
Irrelevant Information Production	The proportion of non-relevant information generated in the planning process. This measure evaluates how much time and effort are wasted on information that does not contribute to effective planning, impacting the overall efficiency.

c. Explainability

The explainability of decisions acts as a crucial metric for evaluating transparency, accountability, and trust in decision-making. When decisions are explainable, it means they are based on clear, logical reasoning that can be easily communicated and understood by all levels of the chain of command. As stated in *MCDP-6*, "commander's intent should convey a clear and powerful image of the action and the desired outcome" (USMC, 2018b, p. 2-11). Clear intent enhances the ability of Marines to execute plans effectively, as they are more likely to engage and take low-level initiative when they understand the objectives and reasoning behind their orders (USMC, 2018b, p. 3-7). Furthermore, explainable decisions allow for an environment where trust is reciprocal. Subordinates must understand the commander's intent and be able to act with little oversight while commanders must provide guidance and the support to allow subordinates to exercise initiative (USMC, 2018b, p. 3-10). Explainability ensures that every member of the team understands the *why* behind decisions, reinforcing trust in leadership's competence and intentions. In the complex and often uncertain environment of military operations, the ability to articulate decisions, justify decisions, and develop trust becomes essential for maintaining discipline, morale, and unity of effort (USMC, 2018, p. 3-11). In Table 3 are measures of effectiveness and performance used to evaluate this theme.

Table 3. Measures of Effectiveness/Measures of Performance Associated with Explainability

Measures of Effectiveness / Measures of Performance associated with Explainability	
Ease of Critiquing Inputs	The ability to clearly identify and critique the inputs used in the planning process. This measure evaluates how transparently inputs are presented and how easily they can be questioned, fostering an open, iterative planning process.
Output Comprehensibility	The extent to which the outputs or decisions derived from the planning process make sense. This measure assesses how understandable and logical the planning outputs are, ensuring stakeholders can follow and accept the decision-making process.
Explainability-Driven Trust	The degree to which explainability enhances trust in the planning process. This measure assesses how effectively the planning process's transparency, clarity, and rationale contribute to trust and confidence in the agent's decisions.
Feedback Mechanism	The ability of the planning process to incorporate feedback from stakeholders and make iterative improvements.

2. Decision Dilemmas Encountered

Using the themes of time, planning thoroughness, and explainability, there are multiple decision dilemmas that the MAG encounters during the modern-day version of vignette 1.

A common dilemma that impacts decision-making throughout vignette 1 is the constraint of time for the MLR and MAG to plan their operation. The Marine planners in the vignette are constrained to develop a plan within 24 hours. Utilizing the MCPP, it is possible to develop an executable plan in 24 hours, however, steps in the planning process may be streamlined and not as thorough compared to a situation where planners have more time. Specific for planning short-fused operations, the Marine Corps' rapid response planning process (R2P2) is designed to conduct planning in six hours prior to execution of an operation. As stated in *Marine Corps Warfighting Publication – 5–1 Marine Corps Planning Process*, R2P2 is dependent on (USMC, 2020, p. 105):

1. Significant MCPP knowledge and experience
2. Detailed preparation, training, and organization of the force and equipment
3. Intelligence and mission planning products developed previously
4. Current intelligence information
5. Refined, well-rehearsed standard operating procedures (SOPs)

The future of Marine Corps aviation demands that the MAG becomes adept at executing rapid planning, with standard operating procedures tailored to support operations within the context of EABO. While time remains a critical constraint in planning, effectively managing it can reduce uncertainty. However, it is crucial to strike a balance between the thoroughness of planning and the need for swift action to capitalize on opportunities faster than the adversary.

Another issue that the vignette highlights is a culture within military planning to only develop three COAs. The culture of developing three COAs is commonly driven by time constraints but can result also in the narrowing of ideas and risks, overlooking innovative or out-of-the-box options. The concept of only developing three COAs can simplify decision-making for the commander, but also reduces optionality and optimality. Ultimately, the decision to limit COAs should consider the specific context of the decision, the available time for planning, and the need for innovation versus speed and clarity in execution.

In vignette 1, the MAG encounters an interruption of communication services that degrades their ability to communicate and plan. Being able to share information is critical for planning, especially if planners are not co-located or coordination must be conducted at a distance. Commanders and their staff must develop network restoration priorities and must understand how their information is communicated across the operational environment. Without the ability to communicate effectively, decision-making is directly affected. Even if a decision can be made, it must be communicated to the individuals and subordinate commanders that will be executing said decision. Every effort should be made to enable communications between decision-makers and the executors. However, if communications cannot be reestablished, or prior knowledge was known that communications were to be degraded, the importance of mission command thus becomes relevant with subordinates carrying out commander's intent.

An executable plan is better than no plan at all. Vignette 1 highlights various issues and dilemmas faced by the MAG during their operational planning. The subsequent section introduces DCAO concepts from the future iteration of vignette 1, presenting innovative ideas and technologies designed to enhance decision-making in Marine Corps aviation and secure a decision advantage.

3. DCAO Improvements

Continuing with the same themes of time, planning thoroughness, and explainability, the future version of vignette 1 intends to show improvements in decision-making through the use of DCAO concepts and technology.

The constraint of time is fixed once a specific duration is allocated. Therefore, it is crucial to use this allotted time efficiently. This is where the use of artificial intelligence, automation, and other intelligent agents can be used to support planning. In the future vignette, the MAG utilizes an advanced planning aid (APA) to assist with planning and generating COAs. An AI decision-making aid can significantly enhance the speed of planning by automating complex data analysis and pattern recognition tasks. By rapidly processing vast amounts of information from diverse sources, AI can quickly identify feasible COAs, predict potential outcomes, and highlight risks, thus reducing the time needed for human analysis. This allows Marines to focus on decision-making rather than data processing, accelerating the overall planning process. Additionally, AI can provide real-time updates and adjustments to plans based on new incoming data, ensuring that operations are conducted with the most current and relevant information.

From the CSBA’s 2020 article *Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems to Implement Decision-Centric Operations*, the use of utilizing AI decision aids for processes such as COA development and tasking falls under the concept of Context-Centric C3 (Clark et al., 2020, p. viii). Figure 11 is an example of Context-Centric C3.

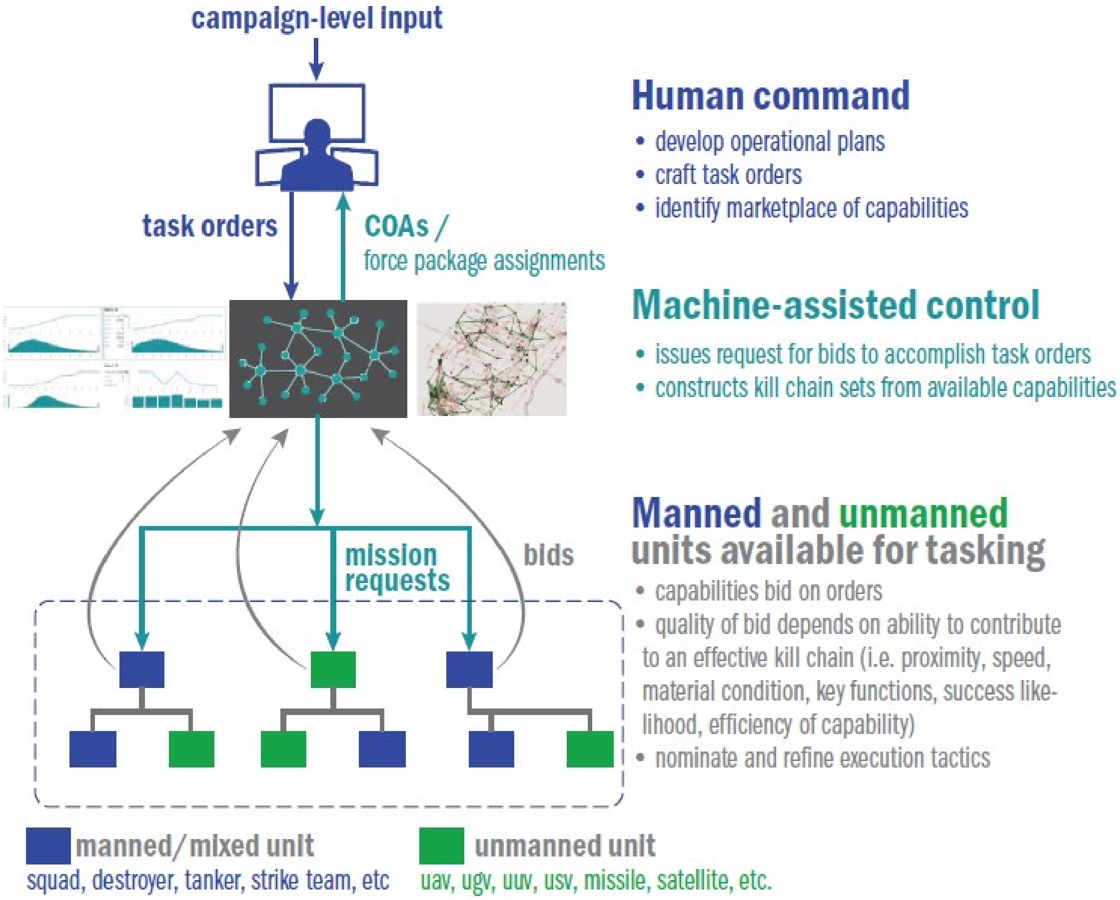


Figure 11. Context-Centric C3 Approach. Source: Clark et al. (2020).

Using Context-Centric C3, Marine planners can provide initial intent and direction to the AI, which in return provides COAs based off the planner's input as well as capabilities available to the unit, such as the MAG. However, critical to this approach is the necessity to be able to clearly provide commander's intent, end state, and tasking in a digitized form that could be also shared between other networked AI systems. Additionally, AI decision support aids would need to be networked to various databases and would require high quality data to complete analysis.

Another benefit of utilizing AI and machines to assist with the process of developing COAs is the ability to produce multiple COAs rapidly. As previously mentioned, planners have often been limited to producing three COAs due to constraints on time and human cognitive load (Nagy, 2022). However, with AI integration, this constraint is significantly reduced. AI can process vast amounts of data at speeds incomparable to human capabilities, enabling the generation of a wider range of options in a shorter period. This rapid data processing allows for more thorough exploration of potential adversary strategies, taking into account a broader array of variables and intelligence. As a result, planners can break away from the conventional limitation of creating only a few COAs. Moreover, an advanced planning agent would generate measures for each course of action for easier comparisons by planning staff.

In the modern-day version of vignette 1, the MAG's ability to communicate was degraded which affected their ability to maintain situational awareness and C2 their forces. Continuing with Context-Centric C3, *Mosaic Warfare* redefines traditional military command structure by prioritizing communication availability over centralized C2 structures (Clark et al., 2020, p. 38). A Context-Centric approach would favor the use of decentralized wireless networks that can handle various communications and network protocols to pass information. (Clark et al., 2020, p. 39). The use of AI tools could assist decision-makers in passing information in a communication denied and degraded environment as well diffuse decision-making down to the appropriate level where communication is possible and aligns with the commander's delegation of authority. As *MCDP-6* states, Marines are doctrinally trained to conduct mission-command and carry out commander's intent (USMC, 2018b, p. 3-6). With the use of AI, human guided machine-enabled control systems could delegate authority to junior leaders, enabling them to manage forces effectively with minimal infrastructure, thus streamlining command hierarchies and improving responsiveness.

Trust is a critical issue when using AI and machines in future application of C3. Research from the *Evaluation of Human-AI Teams for Learned and Rule-Based Agents in Hanabi*, shows that humans often distrust AI if they do not understand how decisions are made by it. To increase confidence and trust in the use of AI tools for decision-making, it is essential that AI produced decisions are explainable. A method for enhancing explainability suggested in *Mosaic Warfare* is the use of a graphical interface that explains the outputs of COAs and other proposed decisions as well as the input data that led to those decisions (Clark et al., 2020, p. 38). In situations as complex as warfare, this approach not only clarifies the decision-making process but also potentially enhances the integration of AI systems. These explanations also make the Marine planner more aware of the realm of possibilities, so that when execution begins, they will be better informed decision makers.

As illustrated in vignette 1, integrating AI into the planning process can provide a decision advantage by reducing uncertainty on the battlefield through enhanced data analysis. This more efficient use of time allows Marines to concentrate on decision-making rather than on problem framing, COA development, COA wargaming, and COA comparison. While it is crucial that humans remain involved as a safety backstop to verify the outputs of AI, accelerating the orientation and observation stages of the OODA loop will enable Marines to make decisions faster than their adversaries, allowing quicker follow-on actions.

D. DESCRIPTION–VIGNETTE 2

Vignette 2 is a continuation of vignette 1 but takes place during the execution of the MLR's EAB maneuver. This vignette follows two rotary wing aircraft conducting escort of a LAW within the Luzon Strait of the Philippines. Within the scenario, the aircraft and their aircrew encounter a number of issues that impact the execution of their mission. Vignette 2 is evaluated through three themes: situational awareness, preparation, and explainability.

E. ANALYSIS–VIGNETTE 2

This section discusses the themes by which vignette 2 is evaluated, the decision dilemmas the operators encountered in the modern-day scenario, and the changes in which DCAO methods solve previous decision dilemmas (see Appendix B).

1. Themes

a. Situational Awareness

Situational awareness in decision-making serves as a pivotal metric for assessing understanding and the ability of those involved to take action in the operational environment. This metric encapsulates the ability of Marines to accurately perceive, comprehend, and anticipate changes on the battlefield for both adversary and friendly forces. Situational awareness is derived from observing the environment, giving that observation context, and developing knowledge from that initial observation (Endsley, 1995, p. 36). Summarized in *MCDP-6*, “Without the information that provides the basis of situational awareness, no commander—no matter how experienced or wise – can make sound decisions” (USMC, 2018b, p. 1-17). High levels of situational awareness enable commanders to make informed decisions and reduce uncertainty on the battlefield. Furthermore, situational awareness as a metric reveals the effectiveness of communication and information systems in conveying critical information to decision-makers and the ability to share information between multiple parties. Good SA reduces decision uncertainty. In Table 4 are measures of effectiveness and performance used to evaluate this theme.

Table 4. Measures of Effectiveness/Measures of Performance Associated with Situational Awareness

Measures of Effectiveness/Measures of Performance associated with Situational Awareness	
Timeliness	The speed at which situational changes are identified and incorporated into the decision-making process. This measure evaluates how promptly situational awareness updates the planning and execution, ensuring decisions are based on current information.
Accuracy	The precision and correctness of situational data utilized in the decision-making process. This measure assesses how accurately situational awareness reflects reality.
Context	The ability to place situational information within the relevant operational context. This measure evaluates how well situational awareness integrates data into the broader enterprise framework, ensuring a comprehensive understanding of the domain-specific mission environment.
Projection	The ability to anticipate future developments based on current situational data. This measure assesses how effectively situational awareness facilitates projection, enabling proactive decision-making and planning.
Surprises	The frequency and impact of unexpected developments that weren’t accounted for. This measure evaluates how well situational awareness can project and mitigate unforeseen events, maintaining stability in planning and execution.

b. Preparation

Preparation, when used as a metric in the context of this vignette, serves as a tangible measure of the aircrews' readiness and capability to perform under varying degrees of uncertainty. This metric encompasses a wide range of factors, including the level of training and proficiency of personnel, the adequacy of logistics and supplies, the condition and readiness of aircraft, and the thoroughness of information known about the operational environment. High levels of preparation provide a robust ability to adapt to emergent situations and adversary tactics. Ultimately, the degree of preparation directly influences the success of Marines on the battlefield and provides additional flexibility during the execution of operations. In table five are measures of effectiveness and performance used to evaluate this theme.

Table 5. Measures of Effectiveness/Measures of Performance Associated with Preparation

Measures of Effectiveness/Measures of Performance associated with Preparation	
Anticipation of Unknown Unknowns	The degree to which preparation accounts for unexpected events. This measure evaluates how well the planning process incorporates contingencies for unforeseen events, minimizing the impact of surprises by the adversaries
Support from Multiple Agents	The number of agents involved in the preparation process and how they contribute to the overall effort. This measure assesses how effectively multiple agents collaborate, ensuring comprehensive support across various areas.
Ease of Use of Agents	The simplicity and intuitiveness of engaging with and directing various agents in the preparation process. This measure evaluates how smoothly the planning process integrates with agents, minimizing friction and confusion.
Recommendation Process	The effectiveness of agents in generating actionable recommendations during preparation. This measure assesses how well agents contribute to the planning process by offering informed and novel suggestions that guide decision-making

c. Explainability

Vignette 2 will also be assessed using the metric of explainability. The primary distinction in this scenario, however, lies in understanding the rationale behind recommendations and decisions made within the brief span of minutes to seconds. The measures of effectiveness and performance remain the same for the theme of explainability.

2. Decision Dilemmas Encountered

Using the themes of situational awareness, preparation, and explainability, the aircrew in the modern-day version of vignette 2 encounter several complex decision dilemmas.

The first significant dilemma arises when one of the AH-1 aircraft experiences a maintenance issue, necessitating a precautionary emergency landing. This reduces the combat effectiveness of the Scarface section and introduces greater risk to the escort operation. This unexpected shift adds stress, increasing the cognitive load on the crew of Scarface 22, complicating their decision-making process. Thrusted into uncertainty, the crew must quickly adapt to complete their mission as a single aircraft.

Another challenge that Scarface 22 encounters is that the crew comes into contact with an unfamiliar potential threat. Upon spotting a periscope, the uncertainty of the mission deepens around how to handle a potential threat that hasn't shown overt hostility. The rules of engagement (ROE) restrict their actions to self-defense and collective self-defense, limiting their response options. They must decide how to manage this potential threat without escalating the situation unnecessarily. Faced with the sight of the periscope, and under restrictive ROE, Captain Boyington and Captain Cunningham decide to perform a show of force. This decision balances the need to deter potential hostile actions without engaging directly, adhering to their engagement rules while attempting to maintain safety.

The final dilemma encountered in the vignette involves the critical need to refuel while escorting the LAW. The unexpected loss of their wingman forces Scarface 22 to continue the mission alone. This operational necessity leaves the LAW temporarily vulnerable as the AH-1 must depart to refuel. This situation underscores the complexities of balancing mission objectives with logistical constraints and the continual assessment of threat levels.

The challenges faced by Captain Boyington and Captain Cunningham in this scenario demonstrate lapses in situational awareness and preparation that put their mission at risk. The sudden mechanical failure and subsequent solo operation reveal a critical unpreparedness for such contingencies, highlighting a need for better pre-mission planning and redundancy in mission-critical systems. Additionally, the encounter with an unfamiliar submarine threat exposes a gap in situational awareness and training specific to emerging threats. Overall, this vignette serves as a case for enhancing planning and training to better equip aircrews to handle unexpected developments and maintain operational integrity under pressure.

3. DCAO Improvements

Continuing with the same themes of situational awareness, preparation, and explainability, the future version of vignette 2 intends to show improvements in decision-making through the use of DCAO concepts.

Uncertainty and the unknowns present significant challenges to the Marine aviators in vignette 2, where decision dilemmas are primarily linked to gaps in the aircrews' situational awareness and mission preparation. In the future scenario, a section of Future Vertical Lift helicopters (FVL) embarks on their mission equipped with an integrated Mission Support Agent (MSA) that is connected to various AI systems, such as the APA described in vignette 1. The MSA enhances situational awareness by participating in the flight planning process from the outset and maintaining awareness of all the background planning for the escort mission. Before disconnecting from the squadron's network and linking directly to the aircraft via a tablet, the MSA receives real-time intelligence and mission updates, ensuring that the aircrew possesses the most up-to-date comprehensive situational awareness to effectively execute their mission.

Next, essential for a pilot's success in the cockpit is the ability to easily gain and maintain situational awareness of the world around them. One technology that assists with developing situational awareness for aircrew are tactical digital information links (TADIL) J. TADIL J is summarized in the *Introduction to Tactical Digital Information Link J and Quick Reference Guide (TADIL J)* as "an improved data link used to exchange near real time information. It is a communication, navigation, and identification system that supports information exchange between tactical command, control, communications, computers, and intelligence (C4I) systems" (Air Land Sea Application Center, 2000, p. I-1). In the future scenario of vignette 2, the FVL section efficiently shares and receives information via Link 16, a form of TADIL J that significantly enhances situational awareness for themselves and adjacent friendly entities. As detailed in a 2005 RAND Corporation article, it was found:

> Interviews with experienced pilots revealed that the improved quality of information under Link 16 improved situational awareness and subsequent decision making in two ways. First, in general, the pilots with access to the Link 16 network reported spending less time building situational awareness (i.e., determining where the Red and Blue aircraft are) than pilots with access only to the voice-only network. In the voice-only network, pilots had to continually listen to voice traffic describing air tracks, mentally convert each description into a velocity and location, predict where the aircraft would likely be over time based on the last report, and perform these mental calculations while listening to further incoming reports. (Gonzales et al., 2005, pp. xxiv–xxv)

As the Marine Corps continues to modernize and acquire aircraft and new technologies, it is crucial that Marine aircraft and C3 systems achieve digital interoperability with Link 16 and future TADIL J networks. This interoperability will enable the swift sharing of information between air and ground nodes, as well as with joint partners in the maritime domain.

During the mission, the MSA also assists in addressing maintenance issues that Scarface 21 encounters shortly after takeoff. The MSA employs a predictive maintenance model that monitors the aircraft's status and identifies potential problems. Rather than forcing the crew to perform a precautionary emergency landing, the AI assesses the airworthiness of the aircraft and advises the pilots, allowing them to make an informed decision about whether to continue flying or land immediately. The AI agent recommends that immediate action is not necessary, and the aircraft can safely reach its scheduled destination. This clear and reasoned advice from the MSA enables the aircrew to concentrate on decision-making and successfully carry out their escort mission.

A growing application of AI is in the area of computer vision. In the future version of vignette 2, Captain Boyington utilizes the sensors of his FVL aircraft programmed with the computer vision program Surveillance, Persistent Observation, and Target Recognition (SPOTR) to detect and classify the unknown periscope as a friendly, Australian submarine. In the 2018 master's thesis, *Concept of Operations for Using Computer Vision Capabilities on Tactical Aircraft*, Justin King investigated the capabilities of adding computer vision features such as SPOTR to tactical aircraft. He found that using an architecture that mainly extracts information without needing to reconfigure onboard electronics via software-based solutions, SPOTR could detect, classify, and identify sensor data and share that information with other networked participants (King, 2018, p. 56). Computer vision capabilities integrated on to tactical aircraft is a force multiplier with the ability to support situational awareness for aircrew, C3 agencies, and intelligence analysists. In sum, it further assists with the clearing of the fog of war on the battlefield. In this case, the FVLs on board SPOTR determine that the periscope is associated with an Australian submarine, and therefore of no threat to the LAW.

At the end of the modern-day version of vignette 2, Scarface 22 must leave the LAW to refuel. In the future version, Scarface 22 deploys an unmanned loitering system (ULS) to fill the gap when the aircraft departs. Unmanned loitering systems (ULS) provide significant advantages in operational settings where there are gaps in manned system coverage. By deploying ULS, Marines could maintain persistent situational awareness without exposing personnel and manned equipment to high-risk environments. These systems are particularly useful in extending the operational reach and endurance beyond what is feasible with manned aircraft, as they could remain in designated areas for extended periods autonomously or under the control of an unmanned systems operator. Furthermore, what separates a ULS from a traditional UAS, is that it is intended to attack targets directly as stated by the UAS company, Uvision (Uvision, n.d.). This capability enables aircraft such as rotary wing platforms to engage targets from further distances, increasing survivability and provides one additional asset on the battlefield to place the adversary as risk.

In conclusion, the advancement and integration of technologies such as AI mission support agents, digital interoperability, computer vision, and ULS in the context of Marine aviation showcase a leap in operational effectiveness and decision-making. These technologies bridge critical gaps in situational awareness and preparation, allowing aircrews to remain aware and proactive in uncertain environments. The future version of vignette 2 illustrates a shift from reactive to proactive management of the battlefield, facilitated by real-time, high-quality data exchange and predictive capabilities. This paradigm shift not only enhances decision-making in the cockpit, but also exemplifies a move towards an interconnected Marine Corps within the joint force. By minimizing the fog of war through enhanced digital interoperability and AI driven insights, Marine aviators are better equipped to navigate uncertainties and execute their missions. The ongoing evolution in tactical aviation demonstrates the importance of embracing technological innovations to maintain superiority on the modern battlefield.

F. DATA, INFORMATION, KNOWLEDGE, UNDERSTANDING (DIKU) IN DCAO

In the dynamic and often uncertain realm of warfare, the ability to rapidly transform raw data into actionable insights is not just an advantage, it’s a necessity. The data, information, knowledge, understanding hierarchy provides a framework for how data can be effectively processed and utilized to enhance decision-making. The DIKU hierarchy is a combination of the traditional DIKW framework found in common literature as well as the Marine Corp’s information hierarchy found in *MCDP-6*. As a reminder from chapter two, data is the collection of signals recovered from earth and space; information is the conversion of the data into something useful; knowledge is information with associated context; and understanding is the addition of projection and expertise to knowledge to infer possible actions. This section explores the application of the DIKU hierarchy within the context of Marine aviation, highlighting how each stage contributes to superior understanding. As demonstrated in the vignettes presented, the progression from data collection to the application of decision-making demonstrates the critical role of advanced technologies and AI in shaping future military operations. Through this exploration of DIKU, this section illustrates how enhanced data processing capabilities can lead to a deeper understanding and more informed decisions, ultimately fostering a proactive confounding causal and surprising effects rather than traditional reactive approach in Marine aviation decision making.

1. Data

In the domain of Marine Corps aviation, the foundation of effective decision-making begins with the collection of raw data. This data originates from a myriad of sources: sensors embedded in aircraft, ground radar feeds, and shared C3 data. Advanced technologies, as illustrated in the future vignettes, play a pivotal role in enhancing these data collection efforts. For example, the integration of AI and next-generation sensors not only accelerates the gathering process but also ensures a broader and more precise dataset. Enhanced digital interoperability between aircraft and C3 systems also allows for the rapid dissemination of collected data to various users that assists with developing situational awareness. By leveraging quality data, hybrid Marine and machine teams lay the groundwork for more sophisticated analysis and interpretation, setting the stage for the subsequent transformation of raw data into information that is both actionable and contextually relevant. Properly deployed, such capabilities, leveraging Moore's Law, can be expected at the tactical edge, not constrained to some permanent Marine Corps Air Station.

2. Information

Once data is gathered, the next step in the DIKU hierarchy is transforming this raw data into coherent, contextual information. This transformation involves the processing and contextualization of data to make it understandable and actionable. Within DCAO, systems like the advanced planning agent, mission support agent, and other AI systems can exemplify this process by converting data streams into a structured commonly-shared format that aircrews and aviation planners can readily use. For instance, the MSA could interpret sensor data to provide real-time updates on potential threats and mission-critical statuses, transforming isolated data points into a clear explainable narrative for the pilot. Additionally, AI tools at this stage can be leveraged to develop and recognize patterns as well as identify anomalies in presented information to enhance analysis. Similarly, wider use in Marine aviation of combat information systems that support instantaneous transformation of data to information facilitates the seamless integration of information across platforms, ensuring that data from various sources shares the same lexicon and is synthesized and disseminated to provide situational awareness to connected users. This layer of the DIKU hierarchy is crucial as it turns single dots on a map into tangible information, allowing pilots, planners, and C3 professionals to reason to gain deep understanding of the operational environment by responding to it more effectively.

3. Knowledge

Building upon the information processed from various data sources, the transition to knowledge involves a deeper semantic reasoning where information is integrated into the existing operational framework through the process of cognition shared between AI agents and decision-makers. In this stage of DIKU, Marines utilize their expertise and contextual understanding to interpret information and develop knowledge. This knowledge is not merely an aggregation of facts, but the interpretation of information derived from understanding meaning, patterns, trends, and implications within the information. With organized, high-quality information, AI planning tools can be prompted to provide projections on adversarial actions or assessments of the operational environment. This projective capability is crucial in the high-stakes environment of peer-to-peer competition where projection and foreseeing surprising effects can provide a decision advantage and can turn the tide of battle. By correlating real-time information with historical analytic trends and human experience, Marines can make well informed decisions that are proactive confounding causal and surprising effects rather than traditional reactive approach, leading to a decision advantage.

4. Understanding

The pinnacle of the DIKU hierarchy in DCAO is understanding, where accumulated knowledge is applied to make sound decisions. This level of cognitive processing involves not just knowing what is happening or what might happen, but also understanding the best courses of action in response to these insights. Incorporating causal thinking through AI decision aids adds a critical layer to this process, allowing AI agents to quickly grasp cause-and-effect relationships within complex operational scenarios that are explainable. Computer vision systems equipped with AI, like SPOTR, integrated with AI agents focused on intervening the surrounding world and applying imagination capacity is a powerful combination. It enables pilots to identify and classify potential threats quickly. This AI enhanced insight helps pilots and decision-makers make well-informed decisions faster, effectively navigating the uncertainty of the operational environment. These decisions are supported by a sophisticated grasp of both tactical and strategic understanding, shaped by past experiences, current intelligence, and causal inferencing. Ultimately, the race to achieve understanding and make actionable decisions in a peer-to-peer environment hinges on the ability to efficiently convert data into understanding faster than previous human cognitive methods.

G. CONCLUSION

In the complex and rapidly evolving realm of Marine Corps aviation, the capacity to make informed and timely decisions is paramount. This chapter has evaluated the decision-making landscape, illustrated by the analyses of two vignettes and further explored through the DIKU framework. The vignettes provided a realistic depiction of current and future operational scenarios, revealing key dilemmas and demonstrating how advanced technologies and methodologies can mitigate these issues. The enhancements described in these vignettes promise a force that is more connected, more aware, and more capable in the face of global threats.

Through the lens of the DIKU framework, it is evident how raw data transforms into actionable understanding, thereby enabling decision-making. With understanding of this framework, integration of advanced technologies such as AI can accelerate the functions of data processing and cognition, which enhances the quality of information and knowledge allowing the human to focus on decision-making. The application of DIKU enables Marines to understand how data transforms when given proper context. Ultimately, this exploration reaffirms the imperative of embracing technological innovation within Marine Corps aviation. This alignment of technology and tactical acumen not only enhances the lethality of Marine aviation, but also ensures the Marine Corps remains a formidable foe for the foreseeable future.

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V. CONCLUSIONS

A. INTRODUCTION

This thesis undertakes a comprehensive exploration of Decision-Centric Aviation Operations within Marine Corps Aviation, focusing on the critical role of decision-making processes across various scenarios. Through the analysis of decision-making in the scenarios of planning and tactical execution in the cockpit, this research provides recommendations structured through the DIKU framework and identifies potential areas for future research in order to support the development of DCAO for the Marine Corps. This research demonstrates the current capabilities and limitations within Marine Corps aviation and highlights the potential of integrating advanced technologies such as artificial intelligence and sophisticated planning systems to enhance operations. These findings emphasize the necessity of an adaptable, robust decision-making framework that can keep pace with both the rapid evolution of operational environments and the technological advancements that are shaping modern warfare.

B. CONCLUSIONS

This research explored emerging technologies, understood evolving Marine Corps decision-making environments, and recommended key enabling investments that set the stage for advanced DCAO within the next generation. Several key fundamentals emerged from the research. First, the temporal dimension significantly influences the appropriate DCAO approach. Planning, inherently a human endeavor, can be assisted by planning agents, which not only reduce the time spent on planning but also enhance the understanding of plans across all staff. Conversely, point defense of an Expeditionary Advanced Base measures success in milliseconds, necessitating a different, semi-automated approach. Other decision-making time epochs exist in between these extremes.

Next, two primary challenges related to DCAO were identified, and the recommendations assume that solutions for these have been advanced in other studies focused on EABO. The first challenge is communications and networking in a degraded, disrupted, intermittent, and limited environment, global positioning system denied environment where connections are problematic and careless use of the electromagnetic spectrum exposes one’s position to their detriment. Determining alternative paths required for communication is beyond the scope of this research. The second challenge involves the collection of data and information at various security classification levels, which can limit sharing if information is stove piped behind classification. Ideally, in a DCAO environment, all data, regardless of classification, should support operational reasoning. Again, addressing this challenge is beyond the scope of this research, but it is crucial for DCAO success that these issues are addressed by another entity.

Building a DCAO foundation should adhere to the DIKU construct. Technologies such as big data, AI support agents, machine learning, reinforcement learning and other advanced learning algorithms only work as well as the foundation they are built on. Decision-centric investment must include AI framework mapped to the DIKU evolution structure; if DIKU compliance is overlooked, success will be fleeting or narrowed to specific micro domains.

Finally, supporting decision-centric technologies needs to be user-friendly, effective, and easy to use. The human-machine interface, human factors, and human-machine teaming aspects must be carefully considered and implemented. Failure to do so means that potentially brilliant agents and algorithms will remain unused and expensive paper weights. This is a significant challenge, as building algorithms requires different skillsets compared to building human-machine teams, which in turn requires different skills for human factors engineering. All aspects are equally important, whereas many current systems emphasize only algorithmic production.

When these fundamentals are observed, Marines employing DCAO can expect many operational improvements. Planning will become much faster and explore far more possible COAs. Each COA will explain the question of *why* causal sequence of events is expected to happen, aiding planners in projecting their decisions into the future with increased confidence. With proper foundation, these planning aids will also enable significantly more efficient and elaborate continuous replanning due to the realization of emergent novel situations in the battlespace. At the platform level, new tools will enable manned platforms to team up with unmanned platforms in all domains, from subsurface to air. Mission agents will keep aircrew informed with knowledge and understanding without overwhelming aircrew with non-actionable data or information, and mission planning tools will enable unmanned systems to understand the digital plans of their human counterparts, acting as backups in situations when autonomous support of humans by machines is necessary.

C. RECOMMENDATIONS

The following recommendations are listed in priority from most important to least important.

The foundational layer of decision-making is data. The following recommendations for data, not specific to Marine Corps Aviation, must be incorporated by the entire Marine Corps as an organization in order to allow for the open and succinct sharing of data to support information transformation. The first recommendation advocates for the Marine Corps' Deputy Commandant of Information (DCI) to spearhead the Marine Corps' adoption of a product-oriented approach to data management, as outlined in the *2023 Data, Analytics, and Artificial Intelligence Adoption Strategy*. According to this strategy, data products should be "designed, built, and maintained with the needs and requirements of its users in mind" (DOD, 2023, p. 8). By viewing data as a product, the Marine Corps will cultivate a culture of data sharing and reuse, governed by stringent standards of accountability, quality, interface requirements, and access controls (DOD, 2023, p.8). This methodology not only facilitates the dismantling of data silos but also prevents the monopolization of data by any single system or entity, thereby promoting broader accessibility. Adopting this methodology will not only ensure proper data management and governance but also significantly enhance future interoperability and situational awareness, thereby empowering human and machine decision-makers with the tools needed for effective, data-driven decision-making.

The second recommendation is that DCI invest into the research and development of a data aggregation tools capable of dynamically self-adjusting in order to digest data of various formats and types. This capability will ensure that data collection keeps pace with evolving data standards and operational demands, thereby reducing errors in data processing and allowing for the processing of various data formats. Similarly, establishing a canonical, commonly shared, multi-dimensional storage to further support data interoperability facilitates more informed decision-making by allowing data to be retained and recalled from various sources and formats. These enhancements are essential for building a robust data infrastructure that supports scalable advanced analytics and decision-making processes in a highly dynamic environment. One example of a robust and dynamic data storage approach is Tile DB (Tile DB, 2022).

The third recommendation is that HQMC Aviation invests into the development of sophisticated AI agents, such as the advanced planning agent and mission support agent mentioned in the vignettes. These agents would leverage real-time data and predictive analytics to enhance continuous planning/replanning and operational support. The advanced planning agent should focus on optimizing COA development and resource allocation, while the mission support agent would provide ongoing, adaptive assistance during missions, adjusting to new information and human guidance. Together, these agents would form an integrated support system, enhancing decision-making capabilities. The development of these systems should involve close collaboration with the Marines that will use the systems to ensure that the technology aligns with real-world needs and enhances rather than complicates mission execution.

The final recommendation, as Marine Corps Aviation continues to advance its capabilities through technology, it is imperative that the procurement of new aviation planning systems places a significant emphasis on explainability and effective human-machine teaming. These aspects are not merely additive but are foundational to the operational success and adoption by Marine Corps Aviation. DCAO relies heavily on the seamless integration of human decision-making with machine-driven data processing and analytics. Effective human-machine teaming should be a core requirement, ensuring that systems are designed to complement and augment human cognition. To further enhance this integration, it is recommended that HQMC Aviation explores the incorporation of causal logic in AI systems. Causal logic can significantly improve the explainability of AI-driven decisions by clearly delineating the reasons behind AI recommendations. This transparency allows operators to understand the underlying mechanisms behind AI suggestions, fostering trust and enabling more informed and agreeable decision-making. Additionally, employing causal logic in AI systems could enhance their capability to detect novel situations and identify previously unknown information in dynamic and technologically evolving operational environments. This adaptability is vital for maintaining situational awareness and making proactive decisions. By leveraging causal logic, AI systems can provide not just predictive analytics but also insights into the cause-and-effect relationships within the data, crucial for planning/replanning and real-time operational contextual adaptation.

D. AREAS FOR FUTURE RESEARCH

Future research within the realm of Decision-Centric Aviation Operations should consider several pivotal areas to advance Decision-Centric Operations. Firstly, it is critical for both Marine Aviation and the entire Marine Corps to delineate and specifically identify its requirements for both tactical and administrative data. A clear understanding of these distinct needs will enable more effective data utilization in operational contexts. Secondly, the development of comprehensive training and education programs on data management for Marines at all levels is essential. Such initiatives will equip personnel to be adept stewards of the data and information that is generated and collected. Thirdly, there is a pressing need to further explore the dynamics of trust between humans and artificial decision aids in both administrative and tactical scenarios. Research in this area should aim to understand and address the challenges of human-machine teaming, with the ultimate goal of enhancing the effectiveness of decision-making in high-stakes environments. Fourthly, future research should focus on identifying the types of information that are not only valuable, but, to prioritization, are critical for commanders' decision-making, distinguishing these from mere informational updates. This involves studying the triggers that prompt decisions and understanding why certain data is pivotal, with the goal of enhancing the design and effectiveness of AI-supported human-machine teaming. Finally, the adoption of artificial intelligence and advanced computational algorithms is not limited to the United States; numerous other countries are also integrating these technologies to support decision-making processes. Data poisoning represents a significant risk where malicious actors add noisy data to manipulate the results of the training conducted within

AI systems, potentially leading to erroneous or biased outcomes. Further research should be conducted into not only identifying potential vulnerabilities within these systems but also developing effective countermeasures to prevent and mitigate the impact of data poisoning.

APPENDIX A. VIGNETTE 1

Figure 12. Luzon Strait. Adapted from Google (n.d.).

A. VIGNETTE 1 (MODERN DAY METHODS)

Scenario: Due to indications and warnings of Chinese forces massing across from Taiwan, the Joint Force Maritime Component Commander has ordered the 3rd Marine Littoral Regiment to re-locate a fires expeditionary advanced base and a sensor EAB within the Luzon Strait of the Philippines. The 3rd MLR has been tasked to complete the re-location of EABs within the next 24 hours. The MAG and subordinate squadrons are tasked with aviation support for the maneuver of the MLR.

During the initial estimate of aviation support to littoral forces, aviation planners at the MAG coordinate with subordinate squadrons, the MLR and the USMC Tactical Air Command Center (TACC) via face-to-face, email, chat, and phone calls to determine the amount of aviation assets needed to support the operation as well as what is the readiness of the MAG.

Following 12 hours of the Marine Corps planning process, countless operational planning teams, and the aviation planning process, the MAG briefs the MLR an aviation estimate of supportability for the MLR's 3 courses of action. The MLR Commanding Officer (CO) determines the COA for the operation will include:

- Movement of the Sensor EAB from location A to location B via Light Amphibious Warship
- Movement of the Fires EAB from location C to location D via LAW
- Security Forces (SECFOR) will need to be established at both new EAB locations prior to the arrival of critical equipment. Movement will occur via assault support
- LAWs will require aviation escort.

The MAG receives their specified tasks and develops their implied tasks:

Specified

- Provide assault support for SECFOR
- Provide escort of LAWs

Implied

- On order, engage Chinese surface / air platforms that threaten EAB maneuver
- Provide intelligence, surveillance, reconnaissance in support of EAB maneuver
- Coordinate with MLR to establish a Forward Arming and Refueling Point (FARP) to support EAB maneuver
- Provide flexible contested logistics plan to support EABs

Following the COA determination by the MLR CO, the MAG loses connectivity with the MLR headquarters (HQ). The MAG executes its PACE plan and re-establishes radio communications and low-rate data bandwidth to the MLR. Due to the communications degradation, the MLR CO determines to execute the Regiments emissions control plan. The MLR and MAG S-2s dive into intelligence reporting to support requests for information and monitor indications and warnings (I&W) of Chinese actions, but due to low bandwidth, intelligence analysis is slow.

At the MAG HQ, situational awareness on the watch floor of the MAG is degraded as the common operational picture from the global command and control system is only receiving intermittent updates due to the low bandwidth. Aviation planners continue planning based on the MLR CO's COA guidance. MAG planners complete the detailed aviation support requirements for the MLR's maneuver and determine:

6x MV-22s are needed to support Assault Support

- 4 aircraft for movement, 2 for spinning back-up
- Cargo: 40 Marines to each EAB location (80 in total)

5x CH-53 are needed to support Assault Support and Air-delivered Ground Refueling (ADGR)

- 2 aircraft for movement of equipment, 1 for ADGR, 1 for spinning back-up, and 1 additional for On-call in-case more fuel is needed
- Cargo: 2 Polaris MRZRs to each EAB location (4 in total)

8x H-1 are needed to support Escort/Close Air Support (deterrence)

- 4 aircraft for escort of 2 Light Amphibious Warships, 4 for spinning back-up

In addition to the required aircraft, aviation planners assess various FARP locations to support the refueling of the escorting H-1s. Due to the communication outage, planners utilize old geospatial imagery for potential FARP locations and landing zones (LZs) from a few weeks before:

FARP site #1:

- Open field, clear of trees, rural – Site A
- Maximum of 2x RW A/C on deck at a time (not including ADGR)
- 1x CH-53 on deck for ADGR

FARP Site #2:

- Filipino Air Site – Site B
- Maximum of 6x RW A/C on deck at a time (not including ADGR)
- 3x CH-53 on deck for ADGR

FARP Site #3:

- Filipino Air Site – Site C
- Maximum of 6x RW A/C on deck at a time (not including ADGR)
- 3x CH-53 on deck for ADGR

Following further assessment of FARPs, planners choose FARP site #1. Site #2, although preferred for size, was denied by Filipino airfield operations due to the airfield being damaged by an USMC AV-8 during exercise Balikatan months before. Site #3 pushes the operational reach of the USMC H-1s and provides too much risk in the event of an in-flight emergency. Site #1 will be able to support the operation, but H-1s will need to be deconflicted by time going in and out of the FARP.

6 Hours prior to the operation, the MAG CO approves the aviation concept of operations (CONOPs). The aviation CONOPs is distributed to the subordinate squadrons and MLR for final planning as well as submitted to the USMC TACC for coordination with the Joint Force Air Component Commander for inclusion into the air tasking order and approval for airspace clearances.

B. VIGNETTE 1 (FUTURE METHODS)

Scenario: Due to indications and warnings of Chinese forces massing across from Taiwan, the Joint Force Maritime Component Commander has ordered the 3rd Marine Littoral Regiment to re-locate a fires expeditionary advanced base and a sensor EAB within the Luzon Strait of the Philippines. The 3rd MLR has been tasked to complete the re-location of EABs within the next 24 hours. The MAG and subordinate squadrons are tasked with aviation support for the maneuver of the MLR.

During initial estimate of aviation support to littoral forces, aviation planners at the MAG use their advanced planning aid (APA), which is connected to the MAG's aircraft maintenance and aircrew databases to provide aviation support estimates of available aircraft for the MLR's various planned COAs. Using a digitized commander's intent and end-state as well as various inputs from force laydown, weather, and intelligence, the APA generates hundreds of aviation estimates of supportability.

Following 6 hours of MCPP and the aviation planning process, MAG planners filter aviation estimates of supportability based off of resource cost and percentage of success. Once a best estimate is determined, the MAG briefs the MLR Command Officer an aviation estimate of supportability which highlight the key actions and events necessary to support the MLR's developed COAs. The MLR CO determines the COA for the operation will include:

- Movement of the Sensor EAB from location A to location B via LAW
- Movement of the Fires EAB from location C to location D via LAW
- SECFOR will need to be established at both new EAB locations prior to the arrival of critical equipment. Movement will occur via assault support
- LAWs will require aviation escort.

The MAG receives their specified tasks and develops their implied tasks:

<u>Specified</u>

- Provide assault support for SECFOR
- Provide escort of LAWs

<u>Implied</u>

- On order, engage Chinese surface / air platforms that threaten EAB maneuver
- Provide intelligence, surveillance, reconnaissance in support of EAB maneuver

- Coordinate with MLR to establish a FARP to support EAB maneuver
- Provide flexible contested logistics plan to support EABs

MAG planners update input parameters and adjust planning assumptions of the APA to ensure the MLR CO's COA is reflected.

Following the COA determination by the MLR CO, the MAG loses connectivity with the MLR headquarters. The MLR's S-6 deploys its artificial intelligence communication aid to reestablish connectivity, following the communication priorities of the MLR CO. The AI communication aid reconfigures the Marines network by shifting SATCOM datalinks to commercial SATCOM and reroutes network traffic. Communication between the MLR and MAG HQs are re-established and data bandwidth is only marginally effect for the MAG. However, due to the sudden loss in connectivity, the MLR CO determines to execute the Regiment's EMCON plan. The MLR and MAG S-2s dive into intelligence reporting to support requests for information and monitor I&W of Chinese actions. Leveraging activity-based intelligence tools, MAG intelligence analysts are able to develop a pattern of life analysis of potential Chinese threats operating in vicinity of the Luzon Strait.

At the MAG HQ, the APA is interfaced with the common operational picture and maintains situational awareness for the aviation planners. With the assistance of the MAG's APA, aviation planners complete the detailed aviation support requirements, which provides the most resource efficient option for the MLRs maneuver:

4x MV-22s are needed to support Assault Support

- 4 aircraft for movement
- Cargo: 40 Marines to each EAB location (80 in total)

4x CH-53 are needed to support Assault Support and ADGR

- 2 aircraft for movement of equipment, 1 for ADGR, and 1 additional for On-call in-case more fuel is needed
- Cargo: 2 Polaris MRZRs to each EAB location (4 in total)

4x Future Vertical Lift (FVL) are needed to support Escort/Close Air Support (deterrence)

- 4 aircraft for escort of 2 Light Amphibious Warships

The APA explains to MAG planners that spinning back-ups will not be required for the operation based off its data inputs of the MAG's readiness. However, due to risk to mission, MAG planners determine that one aircraft and aircrew for each platform should be available. The MAG's APA adjusts resource allocation to support the planners' inputs.

In addition to the required aircraft, aviation planners assess various FARP locations to support the operation:

FARP site #1:

- open field, clear of trees, rural
- Maximum of 2x RW A/C on deck at a time (not including ADGR)
- 1x CH-53 on deck for ADGR

FARP Site #2:

- Filipino Air Site
- Maximum of 6x RW A/C on deck at a time (not including ADGR)
- 3x CH-53 on deck for ADGR

FARP Site #3:

- Filipino Air Site
- Maximum of 6x RW A/C on deck at a time (not including ADGR)
- 3x CH-53 on deck for ADGR

The MAG's APA chooses Site #2 for the operation. Although Site #2 was chosen by the APA, MAG planners filter out COAs using this site due to knowledge that airfield operations will deny use due to the airfield being damaged by an USMC AV-8 during exercise Balikatan months before. The APA chooses Site #1 as the next optimal option and reconfigures flight plans and resources for the operation.

Twelve hours prior to the operation, the MAG CO approves the aviation concept of operations and the MLR CO approves of the operation. The aviation CONOPs is distributed to the subordinate squadrons for final planning as well as submitted to the USMC TACC for coordination with the Joint Force Air Component Commander for inclusion into the air tasking order and approval for airspace clearances. Aircrew flying the mission connect their tablets loaded with a mission support agent (MSA) to download the operation data from the APA. Aircrew use their MSA to complete flight planning, conduct simulated rehearsals, and receive up-to-date intelligence and weather.

APPENDIX B. VIGNETTE 2

Figure 13. Rotary Wing Escort. Source: Bell (n.d.).

A. VIGNETTE 2 (MODERN DAY METHODS)

Scenario: Capt Boyington and Capt Cunningham, callsign Scarface 22 takeoff from the naval airfield and follow their section leader, callsign Scarface 21 to the marry up point with the Light Amphibious Warship. Both aircraft receive routing from the Aviation Command and Control (AC2) node and meet up with the LAW, starting their transit to the new EAB location. The escort to the new location is only expected to take a few hours and during the mission, the section will conduct yo-yo operations to grab fuel at the FARP. The aircrew was briefed prior to the flight that the main red force threat could be potential Chinese Maritime Militia conducting intelligence gathering and harassing actions of other maritime vessels.

Fifteen minutes into the escort, Scarface 21 reports to Scarface 22 that they have an indicator going off in the cockpit that requires them to conduct a precautionary emergency landing (PEL). Scarface 22 stays overhead until Scarface 21 reports “safe on deck,” thereafter relaying information to the AC2 node of the PEL. The AC2 node relays the PEL to the MAG HQ. Scarface 22 receives instructions from the AC2 node to continue with the escort of the LAW and notifies them that the MAG is coordinating the recovery of Scarface 21. Scarface 22 turns around and heads back to escort the LAW.

Returning to the LAW, Scarface 22 cruises ahead at 500 feet AGL. Looking out of the port side of the aircraft, Capt Boyington sees out of the corner of his eye, a wake. Alerting his co-pilot, both Marines are interested in the anomaly and decide to fly a bit closer. Upon visual inspection, both Marines are surprised as they see a periscope poking a few feet out of the water. Immediately, Capt Cunningham radios out to the AC2 node that they have potentially spotted a submarine heading southeast towards the Luzon strait.

While waiting for a response from the AC2 node, Scarface 22 continues circling at a distance, ensuring to keep the wake in view. It appears that the submarine has not yet seen the AH-1 in the overhead. Using their other radio, Capt Boyington alerts the crew of the LAW that they see what appears to be a submarine five nautical miles to the ship's northwest. In response to the alert, the LAW's CO orders the crew to general quarters.

The aircrew of Scarface 22 has never delt with a scenario like this, not even in training. However, they know their mission is to escort the LAW safely to its destination. Currently, the rules of engagement only permit the use of lethal force for self-defense and collective self-defense against hostile act or hostile intent. Are the Marines sure the submarine is even hostile? The AH-1 is loaded with a 20mm cannon and 2.5-inch rockets, but the employment of those weapon systems is a last resort. Knowing that they haven't identified hostile act or intent, Capt Boyington suggests to his co-pilot that they approach the periscope head-on and perform a show of force.

Scarface 22 aligns its nose with the periscope, descends in altitude, and buzzes straight over the suspected submarine. Scarface 22 turns around to conduct another pass, but within seconds the periscope disappears below the waves. The aircrew reports over to the AC2 node that the aircraft conducted a show of force and the last known position of the submarine. Capt Boyington and Cunningham hope that their efforts have deterred the actions of the suspected submarine.

Capt Cunningham checks the H-1's fuel gauge, they need to head to the FARP. The LAW won't have coverage for approximately 45 minutes. As Scarface 22 checks off-station, they feel uneasy. They hope the submarine doesn't re-emerge when they're gone.

B. VIGNETTE 2 (FUTURE METHODS)

Scenario**:** Capt Boyington and Capt Cunningham, callsign Scarface 22 takeoff from the naval airfield and follow their section leader, callsign Scarface 21 to the marry up point with the Light Amphibious Warship. Both aircraft receive routing from the AC2 node via J-series messages and meet up with the LAW, starting their transit to the new EAB location. The escort to the new location is only expected to take a few hours and during the mission, the section will conduct yo-yo operations to grab fuel at the FARP. Prior to departure, the aircrew's mission support agent contains the most up-to-date threat brief prior to being removed from the MAG's network. Contained in the latest threat brief is the intelligence that Chinese Maritime Militia may be conducting intelligence gathering and harassing actions of other maritime vessels. However, the advanced planning agent did gather a data point of anomalous activity in the direction of their flight path.

15 minutes into the escort, Scarface 21 reports to Scarface 22 that they have an indicator going off in the cockpit indicating a potential mechanical issue. Scarface 21's pilot runs a diagnostic using their MSA, which reports the status of the aircraft. The MSA's predictive maintenance model tells the pilot the aircraft is capable of continuing with the mission. Scarface 21 reports to Scarface 22 they are good to continue flying and will troubleshoot on deck when they go to the FARP. The Future Vertical Lift section continues escorting the LAW.

The FVL section cruises ahead at 500 feet AGL. Looking out the port side of the aircraft, Capt Boyington sees out of the corner of his eye, a wake. Alerting his co-pilot, both Marines are interested in the anomaly and decide to fly a bit closer. Upon visual inspection, all Marines are surprised as they see what appears to be periscope poking a few feet out of the water. Immediately, Capt Cunningham generates a J3.3 Surface track and shares it across the Link-16 network. Capt Boyington aims his electro-optical camera towards the periscope and runs the computer vision Surveillance, Persistent Observation, and Target Recognition (SPOTR) program. Using SPOTR, the aircrew with high confidence classifies the periscope as part of an Australian Collins class submarine. Capt Boyington updates the J3.3 track to a J3.4 to indicate a subsurface track.

While waiting for a response from the AC2 node, Scarface 22 continues circling at a distance while Scarface 21 scans for additional threats. It appears that the submarine has not yet seen the helicopters in the overhead. Using J-Voice, Capt Boyington makes sure the crew of the LAW is aware of the subsurface track. The LAW's CO acknowledges that they see the track and are monitoring the situation.

Scarface 21 receives a J-series message response from the AC2 node to leave the submarine alone. Capt Cunningham checks his helicopter's fuel gauge, he needs to head to the FARP. Prior to leaving, Scarface 22 deploys an Unmanned loitering system (ULS) to serve as a wingman for Scarface 21. The MSA provides guidance for the ULS and tells the unmanned system which areas to scan and monitor. Scarface 22 checks off-station and heads to the FARP.

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