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SYSTEMS ENGINEERING CAPSTONE REPORT

APPLICATION OF AN ARTIFICIAL INTELLIGENCE-ENABLED REAL-TIME WARGAMING SYSTEM FOR NAVAL TACTICAL OPERATIONS

by

Rachel S. Badalyan, Andrew D. Graham, Michael W. Nixt,
and Jor-El Sanchez

June 2022

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13. ABSTRACT (maximum 200 words)

The Navy is taking advantage of advances in computational technologies and data analytic methods to automate and enhance tactical decisions to support warfighters in highly complex combat environments. Novel automated techniques offer opportunities for tactical warfighter support through enhanced situational awareness, automated reasoning and problem-solving, and faster decision timelines. This capstone project investigated the use of Artificial Intelligence and game theory to develop real-time wargaming capabilities to enhance warfighters in their ability to explore and evaluate the possible consequences of different tactical COAs to improve tactical missions. This project applied a systems analysis approach and developed a conceptual design of a wargaming real-time Artificial Intelligence decision-aid (WRAID) system capability to support the future tactical warfighter. An operational scenario was developed and used to conduct an operational analysis of the WRAID capability. The project identified requirements for the future WRAID capabilities and studied implementation challenges (including ethical) that will need to be addressed.

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ABSTRACT

The Navy is taking advantage of advances in computational technologies and data analytic methods to automate and enhance tactical decisions to support warfighters in highly complex combat environments. Novel automated techniques offer opportunities for tactical warfighter support through enhanced situational awareness, automated reasoning and problem-solving, and faster decision timelines. This capstone project investigated the use of Artificial Intelligence and game theory to develop real-time wargaming capabilities to enhance warfighters in their ability to explore and evaluate the possible consequences of different tactical COAs to improve tactical missions. This project applied a systems analysis approach and developed a conceptual design of a wargaming real-time Artificial Intelligence decision-aid (WRAID) system capability to support the future tactical warfighter. An operational scenario was developed and used to conduct an operational analysis of the WRAID capability. The project identified requirements for the future WRAID capabilities and studied implementation challenges (including ethical) that will need to be addressed.

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
AI	artificial intelligence
AS	autonomous systems
ASIST	Artificial Social Intelligence for Successful Teams
CE	Cognitive Engineering
CIWS	Close-in Weapons System
CNO	Chief of Naval Operations
COA	course of action
CONOPS	concept of operations
COTS	commercial-off-the-shelf
C-RAM	Counter-Rocket Artillery Mortar
DARPA	Defense Advanced Research Projects Agency
DASNRDT&E	Deputy Assistance Secretary of the Navy - Research, Development, Test & Evaluation
DDG	Guided-Missile Destroyer
DMA	Defense Mapping Agency
DOD	Department of Defense
EVE	Event-Verb-Event
HITL	human-in-the-loop
ISR	Intelligence Surveillance Reconnaissance
JFC	Joint Force Commander
JIPOE	Joint Intelligence Preparation of the Operational Environment
JPP	Joint Planning Process
LPD	Landing Platform Dock
LZ	landing zone
MBSE	Model-Based Systems Engineering

ML	machine learning
MO	main objective
MTBF	Mean Time Between Failure
NATO	North Atlantic Treaty Organization
NATSC	Naval Array Technical Support Center
NAWCAD	Naval Air Warfare Center – Aircraft Division
NPS	Naval Postgraduate School
NRL	Naval Research Labs
NTSB	National Transportation Safety Board
NUWC	Naval Undersea Warfare Center
OIC	officer in charge
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
OV-1	High Level Operational Concept Graphic
PMO	Program Management Office
PRC	People’s Republic of China
R&D	Research and Development
RFI	Request for Information
SE	Systems Engineering
SEC	Systems Engineering Capability
SECNAV	Secretary of the Navy
SME	subject matter expert
SSM	Surface-to-Surface Anti-Ship Missiles
SV-1	System Interface Description
SysML	Systems Modeling Language
TAWC-BREM	The Automated White Cell and Battle Readiness Evaluation Management
ToM	Theory of Mind
TTP	Tactics, Techniques, and Procedures
UAV	unmanned aerial vehicle

US	United States
USAASC	United States Army Acquisition Support Center
USMC	United States Marine Corps
USN	United States Navy
WIP	work in progress
WRAID	Wargaming Real-time AI Decision-Aid
XAI	Explainable AI

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EXECUTIVE SUMMARY

Modern tactical warfare requires swift and effective decisions and actions to maintain the competitive edge in oftentimes highly dynamic and complex battlespaces. The number of factors that need to be considered is magnified by uncertainty, the fast pace of events and the risk of human error. The potential application of automation, artificial intelligence, and game theoretic methods may offer cognitive support to warfighters. This study explored these applications in the form of an automated wargaming decision aid. The team developed a conceptual design of this future system and called it the Wargaming Real-time Artificial Intelligence Decision Aid (WRAID) capability.

The objective of the capstone project was to explore the application of automation, AI and game theory as methods to support a future WRAID capability. The team developed requirements, a conceptual design, and a concept of operations for the WRAID capability. The team identified and explored challenging areas that may present roadblocks to the future implementation of a WRAID capability. The team investigated the ethical challenges and implications related to the use of AI for supporting warfare decisions.

The project began with a literature review of topics relevant to the WRAID capability. The literature review started with a review of AI to provide an overview of how AI works and what type of tasks it is able to accomplish. The review explored human machine teaming as an approach to support the interaction between future commanders and human users with the WRAID system. The need to translate the commanders intent and for WRAID to communicate meaningful outputs back to the commander will require a robust interface. The review included traditional wargaming to study how current simulated wargames are conducted to give insights as to, how a future WRAID capability might replicate aspects of wargames in real-time and with the idea that previous wargames might provide training data for the development of AI and machine learning (ML) algorithms. Training of ML algorithms requires large amounts of representative data. The literature review studied human cognitive loads to provide insight into the cognitive skills and upper limits of the human brain; and to identify the limits of the human mind to show

how AI might provide support. The last topic covered in the literature review was, traditional planning and decision-making to understand, how tactical courses of actions are currently developed in the military.

The team conducted a needs analysis and stakeholder analysis to explore how a WRAID capability might support warfighters. The team developed a set of requirements for the WRAID system based on the needs analysis. The requirements were categorized as: hardware/software, human-machine interface, and ethics. Findings from this first stage of the analysis included: (1) that the complexity of warfare necessitates the development of a future WRAID capability that leverages automated methods including AI, ML and game theory, (2) that the WRAID capability will require significant computational power and complex software algorithms, and (3) that challenges to realization of a future WRAID system will be both technical and ethical.

The conceptual design of the future WRAID system is based on the requirements analysis. The conceptual design was captured in a set of system models that included a context diagram, system views, functional workflow diagrams, and an operational view. The team developed an operation scenario to support an operational analysis of how the WRAID capability would be used in operations.

There are expected roadblocks in developing WRAID. The technology to develop a WRAID system exists, however, the team identified data challenges, AI training, programmatic constraints, and current limitations of systems engineering that will be hurdles that need to be addressed. The data challenge refers to the ability to get sufficient datasets that represent real-world tactical operations and wargaming analysis that are needed for training ML algorithms. Programmatic challenges include the DOD’s ability to implement protocols for cybersecurity, classified data, database access and distribution of information. System engineering roadblocks are new methods that are needed to engineer safe and reliable AI-enabled systems like the WRAID capability. SE methods will be needed to handle unforeseen failure modes and identify root causes early in the system life cycle.

Ethical consideration of an AI-enable system like the WRAID capability is an important factor in the development of the system. Developing the system in lieu of ethics will allow for a greater likelihood of the system being deployed. There are several autonomous weapon systems with ethical concerns that have been pulled from to use as a base for ethics conversation of the WRAID capability. The ethical situation is analyzed qualitatively through an example scenario to see what ethical concerns may come into play in the deployment of a WRAID capability. Ethics plays a huge role in future technology; it is important to build the technology with ethics in mind from the beginning.

Future focus needs to be placed on continuing with a formalized system engineering approach to the imagined WRAID system. The WRAID system will require a robust dataset which will need to be collected and annotated; the more qualitative wargaming data collected the more feasible and accurate the WRAID system will be. Collaboration with military departments is crucial to maximize the benefits of WRAID, such as intelligence and reconnaissance organizations. Simulations for WRAID will be key to refining the system requirements and creating realistic models. Training and documentation on how to use WRAID should be developed simultaneous so the stakeholders specifically the commanders are ready and know how to use this new tool. Areas for future research include cognitive engineering, formal model-based systems engineering, and human-machine teaming.

With the current pace of technological advancements and the goals of foreign nations, AI will play a role in future conflicts and wars. Top-down directives will be needed to engineer and implement a WRAID capability to: provide substantial resources, address operational and cultural changes, restructure systems engineering, and ensure cyber-security and acquisition changes. Realizing a future WRAID capability is not a trivial task. However, it is vital to ensure battlespace superiority now and in the future.

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I. INTRODUCTION

A. BACKGROUND

Advances, proliferation, and the build-up of tactical weaponry and warfare systems by peer competitor nations and by the United States (U.S.) Joint Forces are leading to complexity in warfare. Battlespace intricacy, characterized by increased pace, lethality, and uncertainty, is proliferating as a result of new technologies, capabilities, weapons, and actors (Zhao, Mackinnon, and Gallup 2015). Figure 1 illustrates an instance of complex tactical warfare, showing many varied BLUE and RED force weapons in a close-in ground and urban scenario.

Figure 1. Complex Ground-Operations Battlespace Example.
Source: Fresconi, Schoenfeld, and Rusin (2018).

The escalation of battlespace complexity is causing a knowledge gap in tactical decision-making. U.S. Joint Forces are establishing a presence in previously unrealized places, such as the Arctic Ocean (Larter 2020) and the South China Sea (Jennings 2021). Novel military weapons are continuously being developed, both domestically and overseas. Innovative new threats are emerging such as cyber-attacks, with the United States and

Russia targeting national power infrastructures, as an example (Atherton 2018). Adversarial directed-energy weapons, autonomous systems, advanced intelligence surveillance and reconnaissance (ISR) techniques, and space pose potential risks, hazards and threats that are unfamiliar in a new-age combat environment. Applicable training may not be available, and crews may not be familiar with these new operating environments, leaving a gap in both knowledge and capabilities. This knowledge-gap presents challenges for human operators making tactical decisions, in the form of delays in action, unfamiliarity and uncertainty. These factors all bring new challenges that require a new set of tactics, techniques, and procedures (TTP), rules of engagement and approach logic.

Defense researchers are actively pursuing Artificial Intelligence (AI) as a source of methods, algorithms, and systems that can address the growing battlespace complexity. Researchers are studying the ability of AI to process large amounts of data and information to significantly improve tactical decision superiority in complex combat environments and provide the most accurate information available to the warfighters (Layton 2021). The implementation of AI systems into current military scenarios is at the forefront of warfighter capability and lethality (Vincent 2017). AI has the potential to provide real-time decision responses in complex situations with many variables and unknowns. A real-time decision aid that uses AI to provide wargaming functionality may be able to rapidly produce course of action (COA) recommendations while handling many variables, many scenarios, and many unknowns, in a highly dynamic situation.

Global actors are racing to develop and integrate AI (Forthomme 2019). Considered as the next frontier within both commercial and defense industries, AI is a fundamental step in technological advancement. President Vladimir Putin has stated that whichever country develops AI first will dominate global affairs (Vincent 2017). With the rapidly multiplying number of defense systems and defense operations, human decision making is becoming increasingly more difficult and “narrow”; implying that decisions are not made with all the information at hand, but only a select, readily available portion of it. Losing the race in integrating AI into defense operations is one of the largest risks for the U.S. Joint Forces. To emphasize, Figure 2 displays the Peoples Republic of China’s (PRC) roadmap for the incorporation of intelligent systems (i.e., AI) into both military and socio-economic systems.

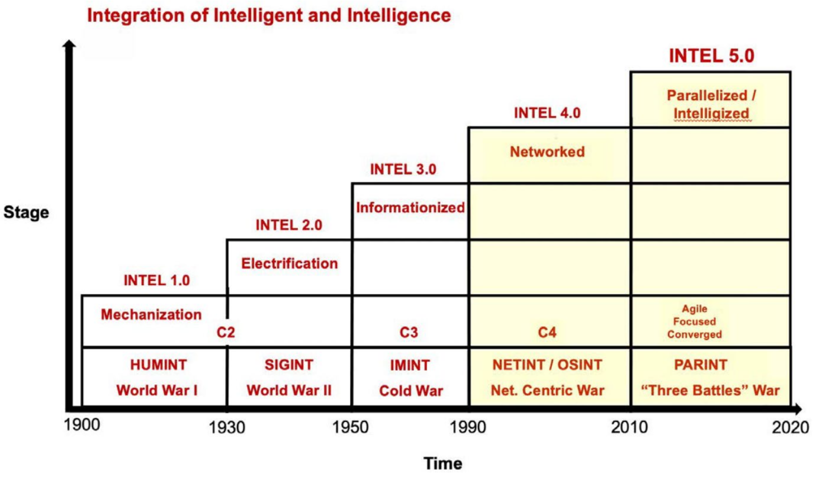

Figure 2. People's Republic of China Integration of Advanced Data throughout the 20th and 21st centuries. Source: Bruzdzinski (2021).

Advances in computational capabilities, AI methods, and increased amounts of information point to potential solutions addressing battlespace complexity through the development and use of automated decision aids to support warfighters making tactical decisions (Johnson 2019). Computers can support human operators by developing recommendations quickly that incorporate large quantities of data that would overwhelm humans. In tactical situations, the time to make critical decisions may be very short and situational awareness may be very limited. Throughout human history, military leaders have strived to command a level of order and predictability during war; "the history of command in war consists essentially of an endless quest for certainty—certainty about the state and intentions of the enemy's forces; certainty about the manifold factors that together constitute the environment in which the war is fought, from the weather and the terrain to radioactivity and the presence of chemical warfare agents; and last, but definitely not least, certainty about the state, intentions, and activities of one's own forces" (Bousquet 2008, 915).

The intent of military operational planning is to develop a series of BLUE force COAs based on Commander's intent and working within many constraints and assumptions. During execution of plans, changes in the situation often require replanning—which entail reprioritizing COAs or implementing new COAs. The use of AI to develop military plans and perform replanning can be referred to as COA engineering. An AI-enabled decision aid has the potential to improve situation awareness and "rapidly replan from the now known information" (Miller et al. 2021, paragraph 6). Without the use of an automated decision aid, the ability to replan is so time consuming and overwhelming, requiring vast amounts of data to be captured and processed to produce an outcome, that it is not performed at all. The potential of an AI-enabled decision aid is that this "approach will enable multi-mission planning across tactical and operational levels, enable a more nuanced way to understand uncertainty about the enemy, and enable replanning so quickly as to make it a viable approach" (Miller et al. 2021, paragraph 7). This will create multiple dynamically updated COAs that change based on critical information and generate insight into operational execution. Figure 3 shows an example of many different COAs that can lead to the overall objective of winning a war.

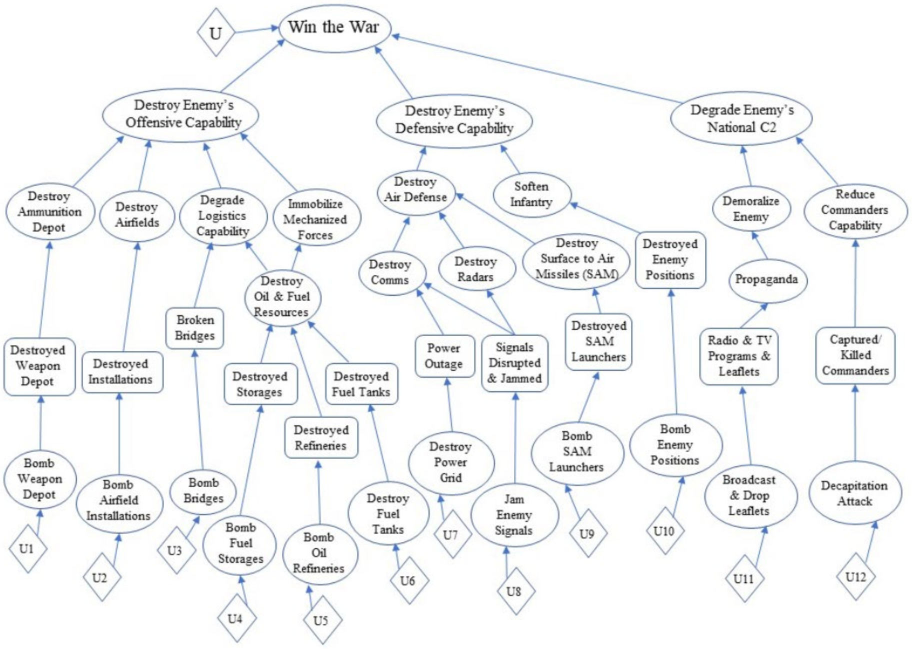

Figure 3. Military Courses of Action Diagram.
Source: Johnson (2020).

B. HISTORICAL EXAMPLES

Naval operations in today's world require sailors and commanding officers to make split-second decisions and reactions in wartime, but currently in times of peace as well. This includes decisions made ashore or at sea. Dramatic and tragic events have occurred that highlight the shortcomings of relying on the human mind to make decisions under extreme pressure and time constraints. The following four recent U.S. Navy catastrophes illustrate the need for automated decision aids to assist and expand the human mental model, even in non-combat scenarios.

1. USS *Fitzgerald* and MV ACX Crystal Collision

a. Incident

On May 17, 2017, the USS *Fitzgerald* (DDG-62) collided with the commercial container ship MV ACX Crystal in Japan. The collision caused the death of seven U.S. sailors and the subsequent flooding of berthing areas on the ship. An approximated $523 million followed in repair costs to the USS *Fitzgerald* (Figure 4).

b. Root Cause

According to the marine accident report completed by the National Transportation Safety Board (National Transportation Safety Board [NTSB] 2017), the following key findings were attributable to the collision:

1. The USS *Fitzgerald* bridge team hesitated to initiate actions early enough to prevent a collision.
2. The communication and cooperation among the bridge team and the combat information center on the USS *Fitzgerald* was ineffective.
3. Combat information center and bridge team personnel were not coordinating effectively.

4. The absence of an automatic identification system signature broadcast from the USS *Fitzgerald* likely contributed to the lack of its early detection by the ACX Crystal bridge team (NTSB 2017).
5. Combat information center and bridge personnel were reportedly fatigued before the incident, impacting their situational awareness and response time.

Figure 4. USS *Fitzgerald* Collision Damage.
Source: Department of the Navy (2017).

2. USS *Connecticut* and South China Sea Collision

a. Incident

On October 2, 2021, nuclear powered submarine USS *Connecticut* (SSN-22) collided with an unconfirmed seamount (underwater mountain) in the South China Sea, resulting in minor to moderate injuries to 11 sailors and undisclosed damage to the vessel (Figure 5) (Chappel 2021).

Figure 5. USS *Connecticut*. Source: Jamieson (2021).

b. Root Cause

Currently undetermined, it has been added by the fleet commander that "whether follow-on actions—including accountability—are appropriate," insinuating that human errors of the sailors onboard were a root cause of the incident (Chappel 2021, 4). A full Naval report is still underway.

3. USS *San Francisco* and Guam Collision

a. Incident

On January 8, 2005, the USS *San Francisco* (SSN-711) cruising at 33 knots, collided with the seabed 350 miles south of Guam, killing one and injuring the majority of 137 sailors aboard (Mizokami 2021). The USS *San Francisco* was on a routine journey to Brisbane Australia using traditional undersea maps:

> the CO of the vessel went to lunch …and the navigation officer, believing it was safe to do so, dived the sub from 400 to 525 feet and accelerated to flank speed. (Mizokami 2021, paragraph 4)

An estimated $79 million in damage to the USS *San Francisco* occurred, as shown in Figure 6.

Figure 6. USS *San Francisco* Damage.
Source: Mizokami (2021).

b. Root Cause

According to a study conducted by the University of Massachusetts Amherst, the commander of the USS *San Francisco* accepts full blame for the incident, but primarily beckons that the navigational charts provided by Defense Mapping Agency (DMA) was last revised in 1989. The commanding officer also acknowledges the lack of forward soundings to ensure the path was clear, and failure to cross-check with other existing sea charts (Drew 2005).

4. USS *Vincennes* and Iran Air Flight 655 Incident

a. Incident

On July 3, 1998, all 290 passengers and crew members perished onboard Iran Flight 655 when the USS *Vincennes* (CG-49) (Figure 7) fired a surface-to-air missile (Wilson 1988). Iran Flight 655 was making a routine journey while USS *Vincennes* was attempting to make warning contact via both military and civilian frequencies, during a time of extreme tension between Iran and the United States.

Figure 7. USS *Vincennes*. Source: Naval History and Heritage Command (1984).

b. Root Cause

According to a report published by students at the Massachusetts Institute of Technology, the accidental death of 290 civilians caused by the U.S. is primarily caused by human error and human and system interface mishaps (Department of Defense [DOD] 1988). Extreme tension between the U.S. and Iran, a predicted Iran attack as reported by U.S. intelligence, and poor human training of the automated systems within the USS *Vincennes* introduced human biases and errors. Ineffective communication between the ship personnel contributed the event. Bias caused by an Iraqi fighter-jet attack on the USS *Stark* (FFG-31) in the year prior caused the officer to speculate an attack was imminent. Only seven minutes elapsed between the first attempt of communication, to the firing of the surface-to-air missile bound for Iran Flight 655 (DOD 1988).

C. PROBLEM STATEMENT

Artificial Intelligence has advanced and grown by leaps and bounds in recent times. There exists a need to develop and incorporate AI as an emerging technology into real time wargaming decision aids. The reason to investigate both AI and automated tactical decision aids in Navy domains is three-fold:

1. Modern battles and weaponry require swift decision and actions to maintain the competitive edge while evaluating a wide scope of potential actions. These speeds are beyond the cognitive skill of a human being.
2. Peer competitor nations are already investigating the use of AI and automated decision aids into their military decision-making process.
3. Potential exists for artificial intelligence to revolutionize the tactical decision-making process, given AI is incorporated into a real-time wargaming system.

D. RESEARCH QUESTIONS AND DELIVERABLES

The primary objective of this capstone project was to address the problem statement by exploring a wargaming real-time AI decision-aid (WRAID) capability as a system that can revolutionize naval tactical decisions. The team developed a set of secondary objectives in support of the primary objective:

- To study the WRAID as a system: identifying its system boundary, inputs, outputs, and external relationships.
- To understand how AI methods can enable the WRAID capability.
- To understand human-machine teaming aspects of the future WRAID system, including human-machine trust, AI explainability, and human versus machine cognitive skills.
- To identify and develop a military operational scenario to support the analysis of the WRAID system to meet warfighter decision needs.
- To study ethical considerations related to the use of an automated AI-enabled WRAID system that supports warfare decisions.

E. PROJECT APPROACH

The capstone project was conducted during a nine-month period from October 2021 to June 2022. Figure 8 shows an overview of this timeline highlighting major project events including needs analysis, development of use cases, concepts analysis, conceptual design, and writing this capstone report. The project was divided into three quarters: fall, winter, and spring. During the fall, the team conducted the needs analysis, identified use cases and reviewed prior work. During the winter, the team analyzed concepts, developed a conceptual design and architecture, and began work on this report. During the spring quarter, the team finished the project and finalized the report.

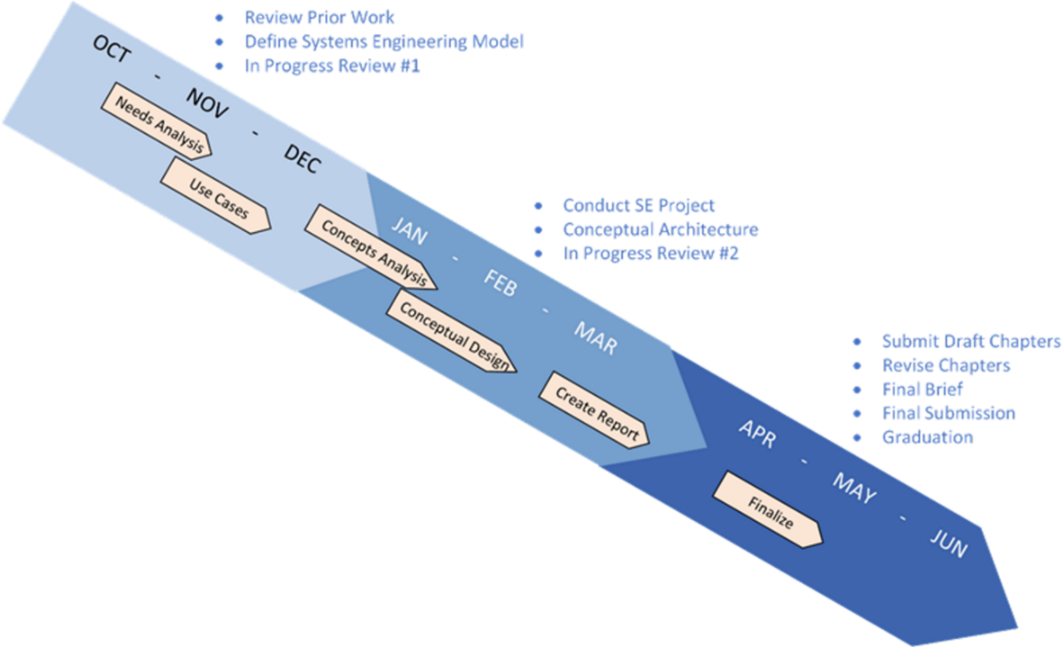

Figure 8. Capstone Project Timeline and Milestones

The team developed a project approach to conduct this system engineering analysis. The approach had three phases, as shown in Figure 9. The first phase was a needs analysis which included literature review, stakeholder analysis, and the development of WRAID requirements. The second phase was the development of solution concepts—this phase produced systems engineering artifacts including a conceptual design and architecture and an operational scenario to support the analysis. The third phase was focused on implications of AI—this phase studied engineering and ethical considerations of the WRAID system.

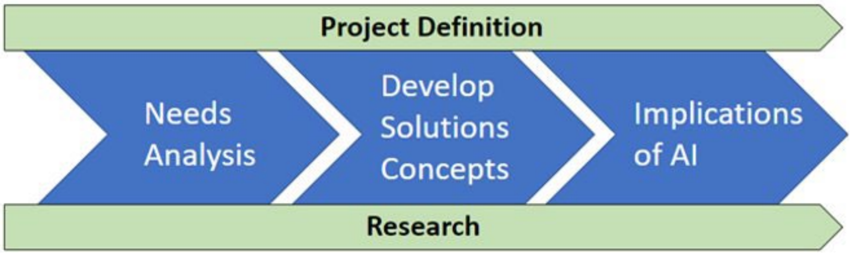

Figure 9. Capstone Project Approach

F. TEAM STRUCTURE

This capstone team, called "Super Team 6," consisted of four team members from diverse backgrounds and different geographic locales contributing virtually. The team had two Naval Postgraduate School (NPS) advisors who provided guidance throughout the process. Figure 10 shows the team's organizational structure, and Table 1 contains a list of the advisors and team members and defines the team roles.

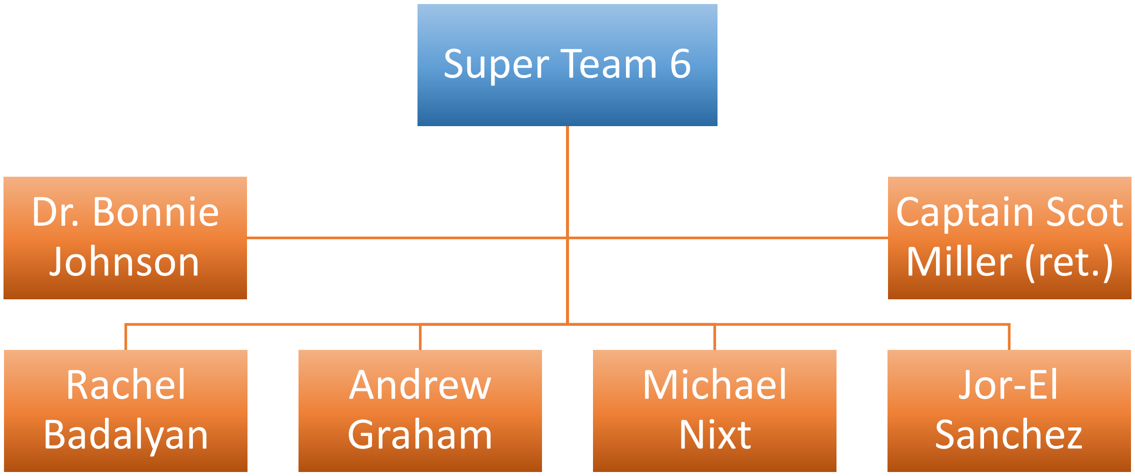

Figure 10. Super Team 6 Structure and Organization

Super Team 6 previously collaborated on other projects at NPS and found the flat hierarchical team structure to be the most effective. The members shared project responsibilities. Weekly team meetings were held, and in-progress reviews were conducted to provide updates to research sponsors.

Table 1. Table of Team Members, Roles, and Organization

Name	Organization	Role	Role Description
Dr. Bonnie Johnson	Naval Postgraduate School	Advisor	Lead Team through Capstone
Captain Scot Miller (ret.)	Naval Postgraduate School	Advisor	Guide Team through Capstone
Rachel Badalyan	Engineering Manager for the Naval Array Technical Support Center (NATSC), Naval Undersea Warfare Center (NUWC) in Newport, RI	Lead Editor	Lead Weekly Meetings
			Setup Communications Structure
Andrew Graham	Mechanical Engineer for the NAVAIR Additive Manufacturing Integrated Project Team, Naval Air Warfare Center—Aircraft Division (NAWCAD) in Patuxent River, MD	Team Leader	Weekly updates to Capstone Advisor
			AI Domain Exploration
Michael Nixt	Mechanical Engineer and Support Equipment Engineer at the Naval Air Warfare Center—Aircraft Division (NAWCAD) in Lakehurst, NJ	Lead Analyst	Data Generation
			Configuration Management
Jor-El Sanchez	Mechanical Engineer for the NAVAIR Additive Manufacturing Integrated Project Team, Naval Air Warfare Center—Aircraft Division (NAWCAD) in Patuxent River, MD	Lead Modeler	Analysis
			Data Plotting

G. CHAPTER OVERVIEW

Chapter I of this capstone report contains a synopsis of the project background, the problem statement, the project objectives, and an overview of the project approach and team organization. Chapter II provides a summary of the team's literature reviews—encompassing key topics critical for the understanding of the WRAID system. Chapter III begins the needs analysis of the WRAID system by utilizing a systems-engineering approach, including stakeholder identification and requirements generation. Chapter IV contains the conceptual design of an idealized WRAID system, with accompanying model-based systems engineering diagrams and example scenario walkthroughs. Chapter V is a short introduction into the ethics of AI in the Naval scenario, with references to commercial AI capabilities (ex. self-driving cars). Chapter VI concludes the report and provides a summary of findings, further work, and recommendations to the U.S. Naval community.

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II. LITERATURE REVIEW

A literature review of various topics regarding aspects of the WRAID system was completed before the specific discussion into the WRAID system was begun. The literature review contained citations to academia research, and ongoing reports of development of AI and AI-related subjects within private industry. The information gathered during the literature review was used to support the following discussion on the WRAID system.

A. GENERAL AI

There is a lot of confusion around AI, as most do not understand what it actually is, or group all "automated actions" in one lump when there are vast differences in the technology. AI is already present in our everyday lives from automated home assistants to chat bots. Militaristically speaking, the future is now. Integration of AI systems is already taking place in various military assets ranging from image processing to missile systems, and unmanned vehicles (Stewart 2018). Incorporating AI and AI-enabled equipment into the next generation of systems is no longer a luxury, it is a necessity. The systems of today have AI capabilities and should be emphasized during system development. More must be done to incorporate AI's advantages into military strategies. Steps should be taken to anticipate and mitigate the risk and vulnerabilities that accompany AI's attributes. As the race to AI continues, we must begin to exploit the gains AI can provide today while planning for the benefits it will provide in the future. For the implementation of the WRAID system to be effective, several tenets of AI are considered to be imperative to the succesful incorporation of AI in the near term. Multiple AI topics have been detemined to be critical to ensure a realizable system while conceptualizing the design of the WRAID system.

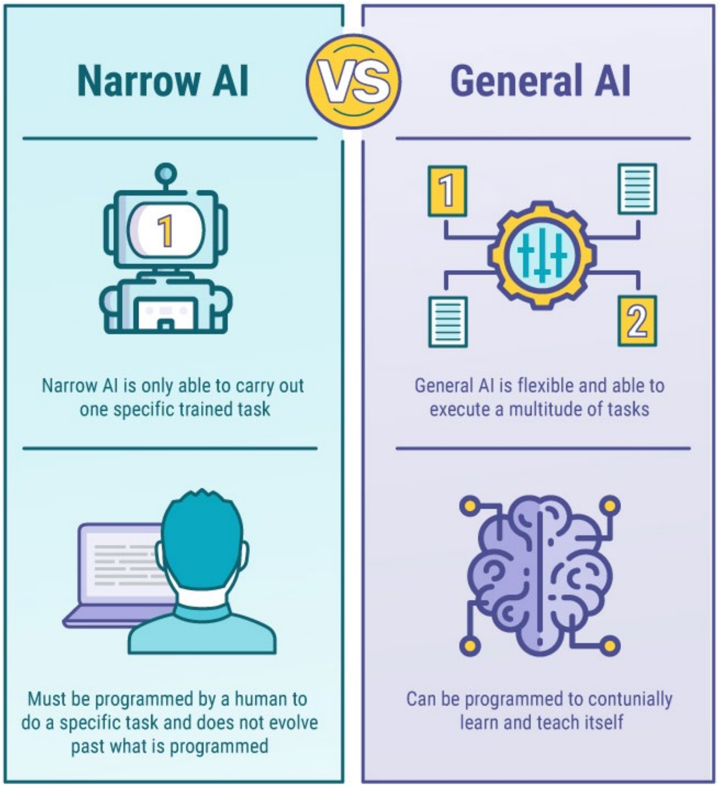


Figure 11. Narrow AI vs. General AI. Source: Soler (2019).

AI can be broken into two (2) categories, Narrow AI and General AI. Figure 11 displays a graphic representation of the basic key differences, and Table 2 provides characteristic differences. Narrow AI, also called Modular AI, is common place, and reactively responds to input via static programing. They are narrowly focused in a particular domain, performing one task at a time. Narrow AI cannot utilize existing knowledge across multiple domains, and apply the algorithm, or knowledge, towards new situations. General AI, which is not yet in use, theoretically can accomplish multiple tasks, and is able to apply previously learned behaviors to new situations and "in circumstances other than the task it was designed" to execute (Burton and Soare 2019, 6). The overarching goal of general AI is to replicate the human characteristic of intelligence, "to understand and adapt to one's environment, and to learn from previous interactions and situations. Intelligent machines will be able to perform complex tasks, be able to learn and improve operationally over time, and do so without human input" (Burton and Soare 2019, 5).

According to one source, in this future state, general AI "has the ability to understand context, to successfully apply information and behaviors learnt in one context to other situations it encounters, and in circumstances other than the task it was designed to perform. In this category, intelligent machines will be able to adjust behavior depending on interaction with people and other technologies and understand the context, motivations, and complex intentions of these actors" (Burton and Soare 2019, 5).

Table 2. Narrow AI vs. General AI. Adapted from Techopedia (2021).

Current State Narrow AI	**Future State General AI**
Application-specific, limited task	Non-application specific, intelligent action
Fixed models	Interacts with operating environment
Learns from thousands of categorized data samples	Learns from few, often unstructured, data samples
Repetitive tasks with no understanding	Complex functions replicating the full range of human cognitive abilities
No transfer of knowledge across domains	Leverages knowledge from one domain, applying to new domains & tasks

B. HUMAN-MACHINE TEAMING

Human-machine teaming is a relationship between the human, the machine, and the interactions and interdependencies between them (Konaev and Chahal 2021). To further refine the concept, humans and AI-systems working together in a cooperative environment, where both parties are aware of the other's strengths and limitations, building trust in each other's competencies, to achieve better decision making. In an ideal human-machine teaming environment, AI systems serve as intelligent trusted members of the collaborative team, rather than a tool or piece of equipment.

Beginning in the lower left of Figure 12, interaction between humans and AI is unidirectional, only flowing from the AI to the human. Currently systems produce results in the black box form, where only outcomes are provided. To move forward in creating a collaborative teaming environment, the results need to include transparency providing both outcomes and processes. Following transparency, human-AI interaction will proceed bi-directionally, where initially the humans can query the AI to explain something, imparting explainability and progressing to self-explaining. According to one source "In this stage it is not only the human that can express a need for information, but also the AI that can voluntarily provide information, for example when it detects misunderstandings, possible errors of judgment (e.g., bias), or unjust exclusions of COAs during planning" (Bosch and Bronkhorst 2018, 8). From there, in bi-directional interaction, the human-AI interrelationship advances to a collaborative state, where both parties are adaptive team members in decision making.

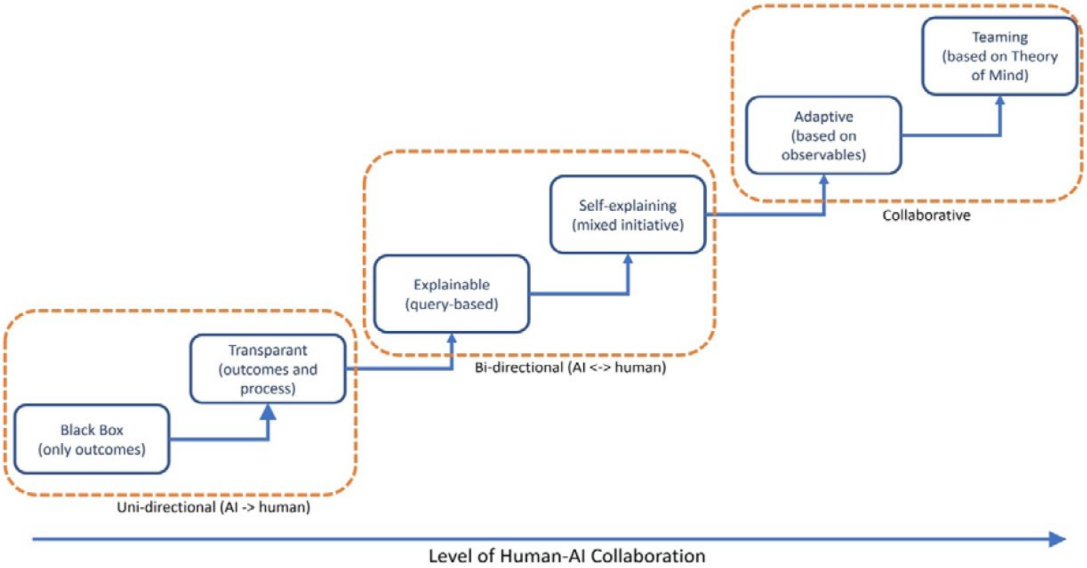


Figure 12. Levels of Human-AI Collaborative Decision Making. Source: Bosch and Bronkhorst (2018).

To reach a collaborative state, trust is required. In the context of human-machine teaming, trust refers to a person's confidence in technology's conclusions. The idea of trust is larger than simply the ability to communicate; a trustworthy AI is transparent, explainable, interpretable, and reliable. Trust is a complex and seemingly abstract concept, and to instill trust in a system one must "build trust into the system" specifically by making AI more transparent, explainable, and reliable (Konaev and Chahal 2021, paragraph 4). To achieve a successful implementation of WRAID, human-machine teaming and trust must be accounted for and built into the system from the ground up. As Figure 12 depicts, this begins with the ability for AI to be transparent and explainable.

C. EXPLAINABLE AI

AI, algorithm, machine learning and neural network calculations are commonly referred to as a "black box." This connotation is attributed to the extensive mathematics required to define the problem model, along with any number of situational parameters, also known as the decision space. The creation of a solution set is not easily translated or understood. The black box model is commonly cited as a hindrance to the future widespread use of AI. People struggle to comprehend how an algorithm came to a result, leaving the user distrustful of the AI's decision. For users of AI to trust that the AI's decisions are correct or necessary, there needs to be some level of explanation of what is being done, so that the user understands and agrees to let the AI do its job (Gunning and Aha 2019). Explainable AI (XAI) employs processes and methods, allowing the user to understand and trust the AI's results (Zornoza 2020). XAI has the potential to mitigate the weariness between human decision-makers and an AI's predictions and recommendations, as the end-user can grasp how the AI made its decision. Incorporating aspects of XAI will impart an essential trust between the warfighter and the AI's predictions, which will encourage the warfighter to embrace the new technology (Zornoza 2020).

"One way to gain explainability is to use algorithms that are inherently explainable. [By using] . . . simpler forms of machine learning such as decision trees, Bayesian classifiers, and other algorithms that have . . . [levels] of traceability . . . in their decision-making" process, the AI can provide the transparency necessary to gain the user's trust

(Schmelzer 2019, paragraph 4). Another way to gain a level of explainability is to define the parameters, which provide the why, when, and how—why was a result selected, why was the result not different, when is there a success versus a failure, how do I correct an error? (Figure 13) (Gunning and Aha 2019). Efforts to provide this information in a transparent and traceable way are necessary to foster a trusting and beneficial collaborative teaming environment. The determining factors of the model will need to be presented during system interaction so that the user is "coming along side" the AI in agreement, rather than questioning the choices and decisions as they move through the decision and recommendation. By employing transparent and explainable AI models, WRAID will inherently begin developing the human-machine teaming environment that is crucial to an effefctive AI system.

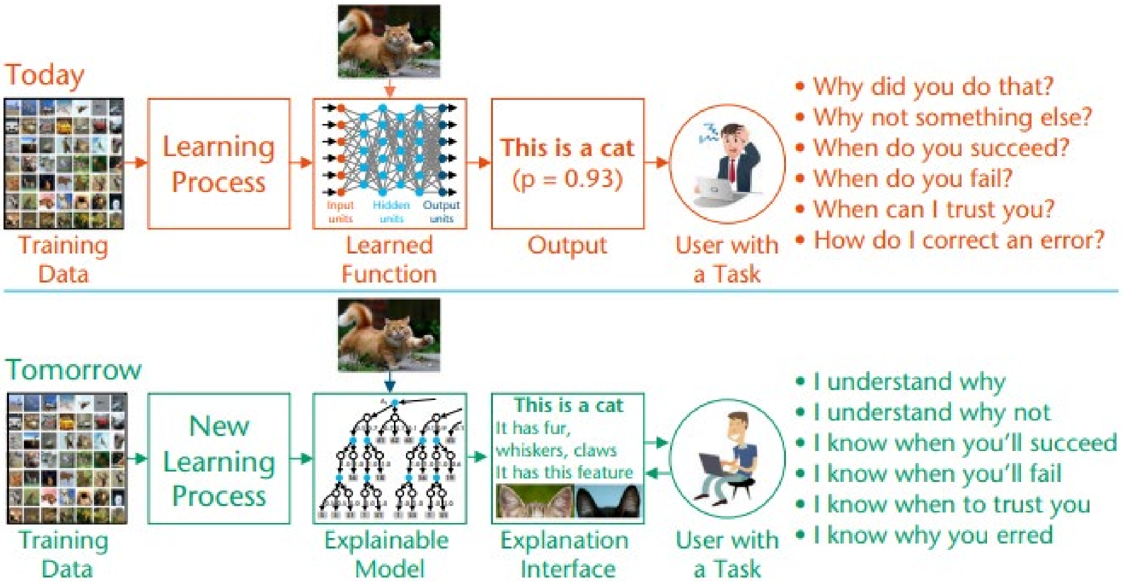


Figure 13. Explainable AI—Today vs. Tomorrow's Scenario.
Source: Gunning and Aha (2019).

D. TRADITIONAL WARGAMING

NATO defines a wargame as "A simulation of a military operation in which participants seek to achieve a specified objective, given pre-established resources and constraints" (NATOTerm n.d., Definition). The term wargaming originally comes from the Prussian word Kriegsspiel, which translates to "war considered as a game" (LBS Consultancy n.d., paragraph 3). Perhaps a more direct definition is "War considered using gaming mechanics alludes to elements such as: rules, objectives, scenarios, processes, players, umpires, analysis, friction, uncertainty, chance and luck" (LBS Consultancy n.d., paragraph 3). The goal of wargaming is "to immerse participants in an environment with the required level of realism to improve their decision-making ability and/or the actual decisions they make" (LBS Consultancy n.d., paragraph 18). Figure 14 depicts a basic wargame taxonomy and establishes the idea that wargaming is effectively, a support tool for decision makers; in both a training (helping decision makers make better decisions) and analytical (helping decision makers make better real-world decisions) environments (LBS Consultancy n.d.).

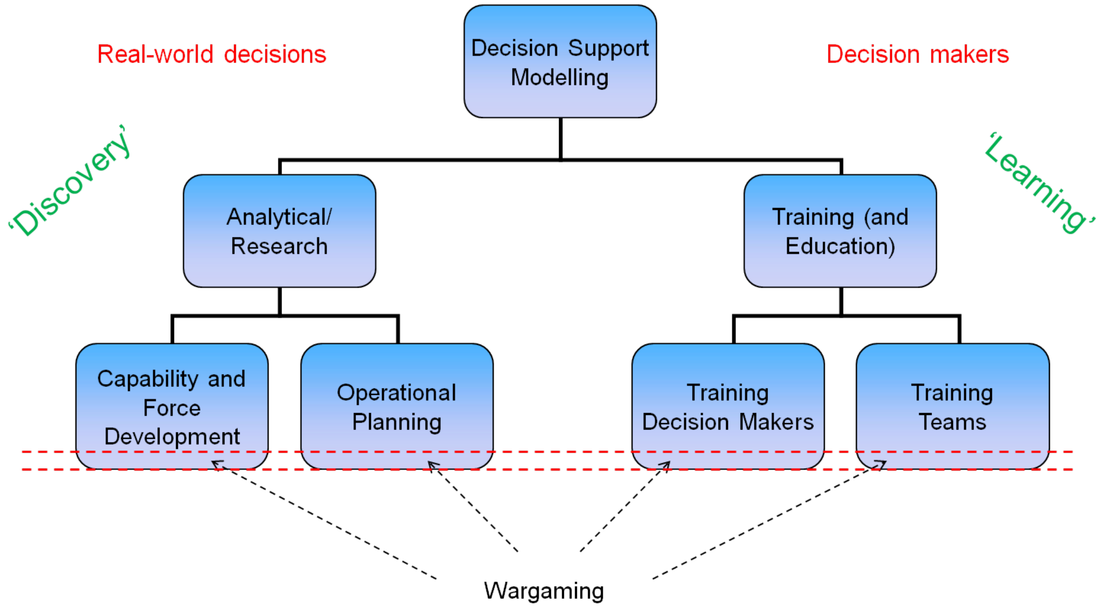


Figure 14. Wargaming Taxonomy. Source: LBS Consultancy (n.d.).

Wargaming is used now to train decision makers, at all levels, strategic, operational, and tactical, to make better decisions. The ongoing progress in AI capabilities, as well as significant improvements in automated systems, has the capacity to change the future of warfare. One source suggests “whereas traditional deterrence has largely been about humans attempting to understand other humans, deterrence in this new age involves understanding along a number of additional pathways” (Wong et al. 2020, xiii). In the new age of AI enabled warfare, humans will need to understand not only the human opposing force, and AI, but also their own AI. Likewise, the AI must repeatably understand the humans and opposing force. When running a futuristic wargame, involving AI and autonomous systems (AS) on both the BLUE and RED force, players assigned to manned platforms were more hesitant to use force and avoid further escalation. However, the speed with which AI & AS determine and carry out a COA may lead to unintentional escalation. In a future where the use of AI & AS is commonplace, the chance of accidental escalation and volatile crisis situations is high. The ability for AI to misinterpret situational cues, based on the AI’s set level of autonomy, could be catastrophic. Additionally, while human casualties increase tension, opposing forces may value a human life differently, reducing the confidence in AI decisions. It was found that the AI tended to overreact with the limited information it has access to. Similarly, an AI’s ability to autonomously deescalate a situation could be deficient.

While still a young technology, significant research has occurred within the realm of AI by experts globally. The United States Marine Corps (USMC) are working to develop Athena, a next generation wargaming machine that implements a smart home assistant type platform for war planning and data gathering. This new technology will provide a tailored and adaptive environment for warfighters to learn. Significant quantities of data will illustrate the risk tolerances and biases of humans the more Athena is used to plan and execute missions. Similarly, as new data is constantly collected, Athena will continue to optimize, model modern military operations, and offer innovative tactics (Benjamin, Cuomo, and Whyte 2018). Today wargaming is used to train and provide analysis of and for humans, going forward as we encroach upon the age of AI enabled warfare, wargaming will provide the data, models and simulations used to train AI and autonomous systems.

E. TRAINING OF AI

Training AI to understand how to interpret the data given produces a more accurate result and gives the AI a more realistic understanding of how the real world operates. Quality data is the most important part of training AI; this will avoid the common saying of “garbage in, garbage out” (Arel, Rose and Karnowski 2010). A major factor in training AI is annotating the data with the required meta data. Data annotation can be compared to hashtags used in social media that enables user searches to find related pictures. Data annotation lets the AI know what is in the picture and create identifiers that give contextual meaning to the AI. Even when the AI system has become mature in some military applications; the data will need to be annotated. The AI system is not going to replace the human in the decision process, but rather change the process in which the decision is based and made.

During the training process, validation of the AI is needed to ensure that when given new data the AI comes to the correct conclusion. This is often performed by giving the AI algorithms data sets with known outcomes and validating that they arrive at the correct conclusion. Past battles, specific to what the AI has been taught to solve can be used. Identifying these past battles and military engagements is imperative. The next step is testing the AI with real world data and repeating this until the AI performs accurately. Testing the AI with real world data will result in conclusions that can be verified by comparing what AI suggested to what happened. This type of testing will require time and produce a feedback loop for corrections to be made to the AI to better simulate the real world (Figure 15).

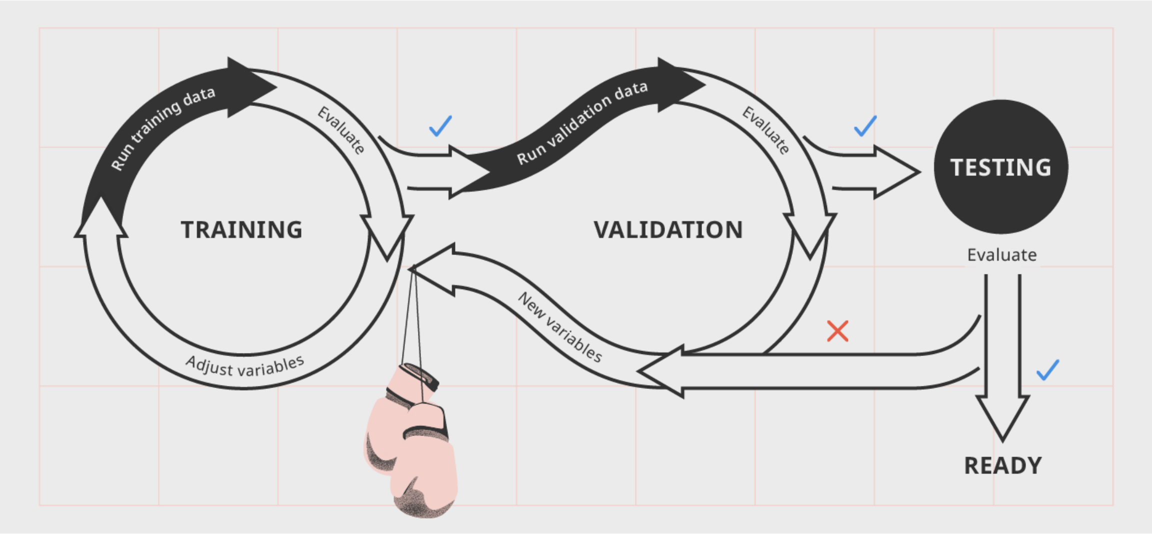


Figure 15. How to Train Artificial Intelligence. Source: Telus International (2021).

Most of the work in AI conducted today occurs during the training phase. It takes the theoretical application and applies it to more practical application. This is where the AI will learn how to behave; the information available will feed into the training of the AI. Examples include how military decisions are made, ethical dilemmas, wargaming, and how the AI will interact with humans. All this contributes to the AI's development. Understanding how the AI will be trained will allow better requirements to be developed. The methods that will be used to train the model will undoubtedly play a role in the system development and sustainment. It is likely that the model will need to be retrained and grown down the road as warfare evolves. AI has its advantages over humans by being able to store and process more data and overcoming cognitive load limitations.

F. HUMAN COGNITIVE LOAD

The human brain is limited by the amount of information that can be stored. The average brain is constrained to five to nine binary digits (bits) of information (Klingberg 2008). These bits of information can be series of numbers, images, sounds, words but each it considered a bit. For instance, recalling the following words "RANGE SOUND HEARING EAR FLIGHT" are considered five bits, not sixteen (the number of letters) this is because the word represents a concept, and the brain does not memorize the spelling of each word. The concept of combining letters like this is called chunking and can be done with any concept asked of the brain. Figure 16 shows the theoretical limitations of the brain, where brain memorization can improve at a logarithmic scale, meaning its improvements will become smaller as it approaches full potential. However, this is not relevant since no one has come close to maximizing their brain capacity.

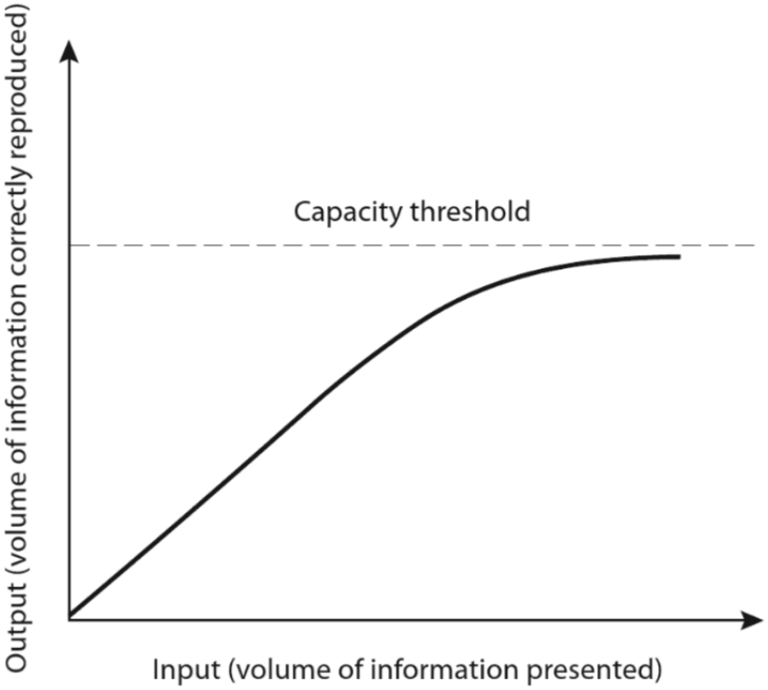


Figure 16. Human Brain Capacity. Source: Klingberg (2008).

The human brain is prone to ignore, forget, or reduce the information used when solving a problem, especially when inundated with information. This loss of information could be critical when commanders are making decisions. An example of the mind ignoring information when under stress is driving while distracted. A parent with children in the backseat making noise, while driving through an active construction zone and up to a stop sign—they stopped, looked both ways, then pulled out onto the road, where they cut off a semi-truck which crashed into the back of their car. The distracting situation and excess noise led to over stimulus. How could they miss the truck, even after looking both ways?

When under stressful and distracting situations, the brain will ignore information with which it is unfamiliar. Simply, their brain chose to ignore the truck (Klingberg 2008). There are numerous examples in the real world where the limits of the human brain cause accidents. This type of problem can be minimized by leveraging a computer-based approach such as AI.

A computer is excellent at storing and analyzing significant quantities of data, simultaneously. When translated to information (no easy task), this can help expand the decision maker's mental model and prevent information loss. An AI based program capable of creating a COA that is based on large incoming and historic datasets can provide insight that the human mind is prone to ignore.

G. TRADITIONAL METHOD OF PLANNING AND DECISION MAKING

The best way to visualize the design of WRAID is to compare it to the traditional joint operation planning process, as outlined by the Joint Targeting School (Joint Chiefs of Staff 2020). A summary of the entire joint planning process is provided in Figure 17. It is a complex procedure with many steps.

While complex and confusing to the outsider, it is straightforward. There is constant consideration being made to ensure the commander's intent is being fulfilled. The process consists of 7 primary steps: Initiation, Mission Analysis, COA Development, COA Analysis and Wargaming, COA Comparison, COA Approval, and Plan or Order Development (shown in Figure 18) (Joint Targeting School 2017).

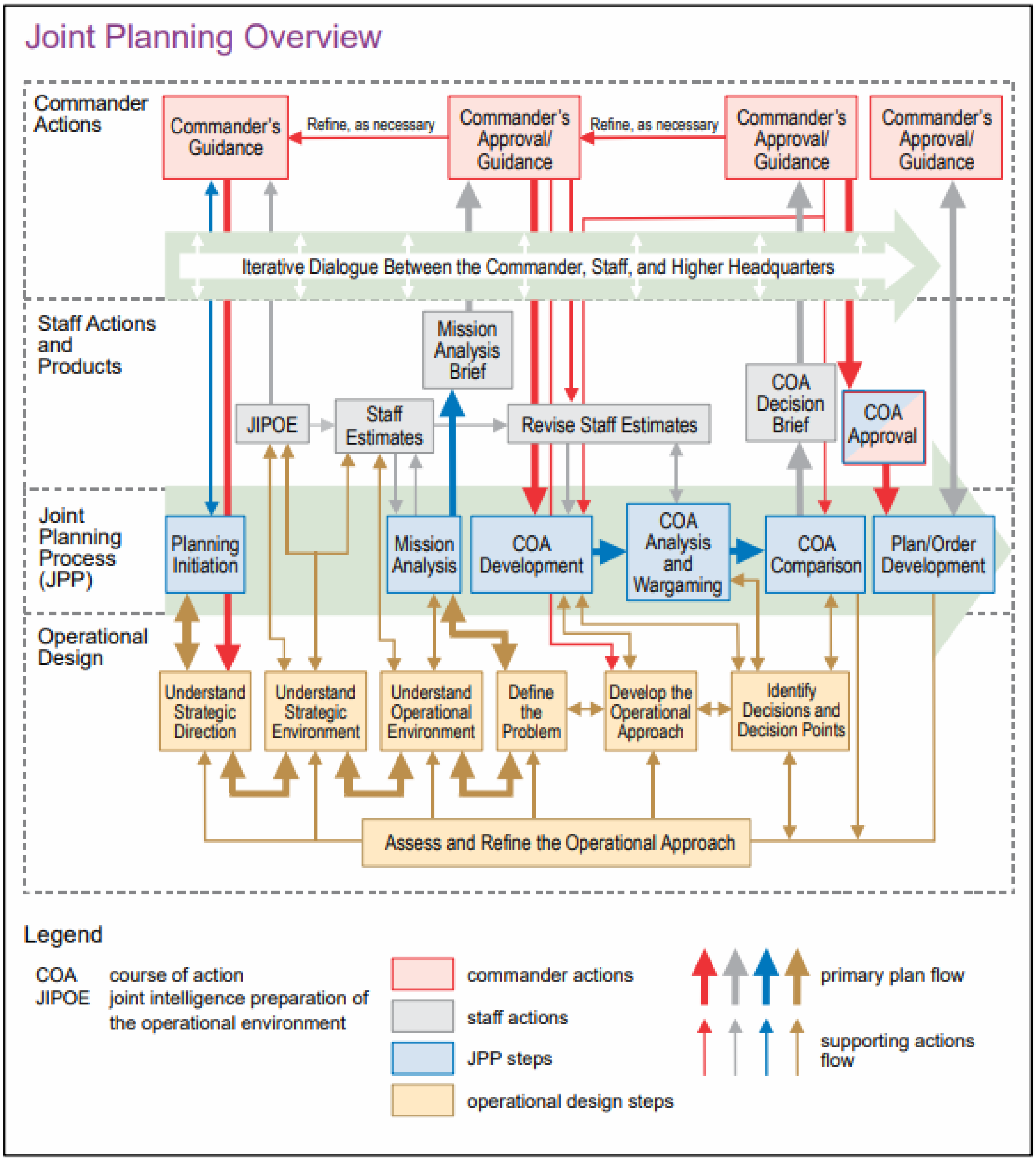


Figure III-2. Joint Planning Overview

Figure 17. Functions and Action Flow Chart for Joint Planning. Source: Joint Targeting School (2017).

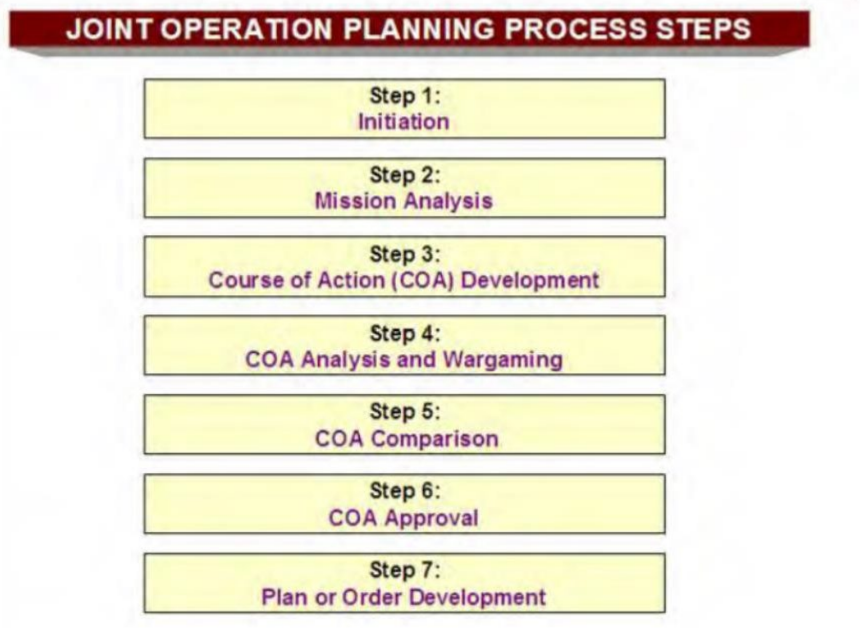


Figure 18. Joint Operation Planning Process Steps. Source: Joint Targeting School (2017).

1. Initiation

Initiation begins when the opportunity for a military capability is recognized which can be employed in response to a crisis or to support a national objective. Staff will take the guidance provided and determine when the mission will take place, the status of assets, and any intelligence available. In this step, the tasking is passed down from the higher levels of authority to lower levels of command. Often, the assigned staff will read back the tasking in their own language, to show the superior staff they understand the tasking. This iteration helps resolve poorly worded tasking and avoid miscommunications and misunderstandings.

2. Mission Analysis

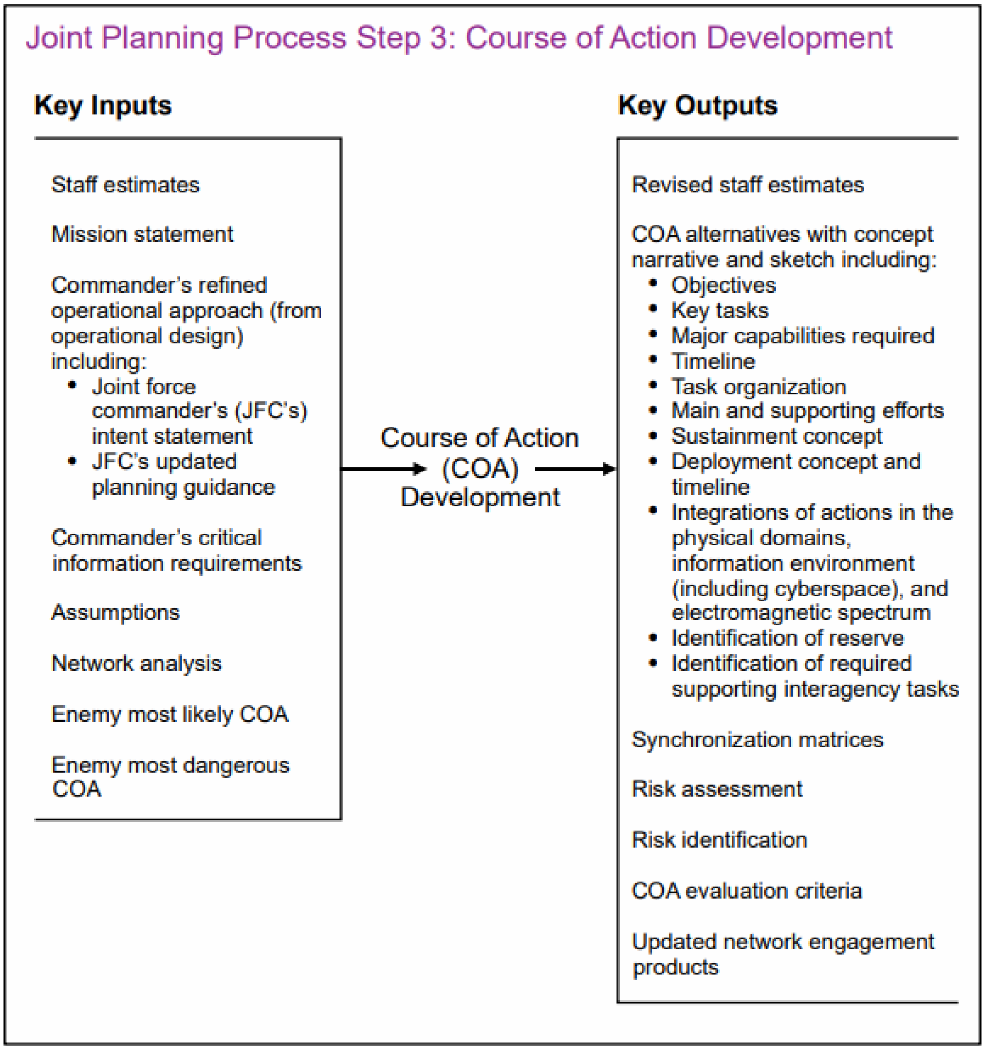
Assigned tasks are studied to ensure other tasks necessary to complete the mission are identified. Outstanding questions are answered, data is gathered, generated, and assembled for further processing. In the first two steps, it is important to identify and interpret the Commander's intent.

3. Course of Action Development

At this point, the staff works to develop multiple COAs. The best COAs will complete the mission, while adhering to the commander's intent, providing numerous tactical possibilities to deal for unpredicted events, and strategically and beneficially poising our forces for future missions (Scot Miller, email communication, January 19, 2022). All COAs developed should be useful, complete, and feasible. The current rule of thumb is to develop three COAs. Time is also spent analyzing previous wargame simulations to see if knowledge could be gained from them and what additional considerations should be made, if any. COAs can be varied by using different force capabilities and end results, providing senior military leaders with various options for cost, risk, and deployments.

Different COAs can be developed by altering the force capabilities through their physical, cyber, or electromagnetic environments. Additionally, the COAs can be developed in such a way that they attain different end states. This allows decision makers to consider options that might have a broader impact on cost, risk, and force deployments. After the COAs have been selected for analysis, they should be considered by how well they meet the following criteria: Suitable, Feasible, Acceptable, Distinguishable, and Complete.

The quantity of information flowing in and out of this step alone is significant. The WRAID system will need to use inputs and outputs like what is shown in Figure 19.



Joint Planning Process Step 3: Course of Action Development

Key Inputs

Staff estimates

Mission statement

Commander's refined operational approach (from operational design) including:
- Joint force commander's (JFC's) intent statement
- JFC's updated planning guidance

Commander's critical information requirements

Assumptions

Network analysis

Enemy most likely COA

Enemy most dangerous COA

Course of Action (COA) Development

Key Outputs

Revised staff estimates

COA alternatives with concept narrative and sketch including:
- Objectives
- Key tasks
- Major capabilities required
- Timeline
- Task organization
- Main and supporting efforts
- Sustainment concept
- Deployment concept and timeline
- Integrations of actions in the physical domains, information environment (including cyberspace), and electromagnetic spectrum
- Identification of reserve
- Identification of required supporting interagency tasks

Synchronization matrices

Risk assessment

Risk identification

COA evaluation criteria

Updated network engagement products

Figure 19. Chart Explaining the Inputs and Outputs of COA Development. Source: Joint Targeting School (2017).

4. COA Analysis and Wargaming

Course of Actions should be analyzed through a process that thoroughly examines the COAs and empowers decision makers to evaluate potential COAs for their advantages and disadvantages. This step is valuable as it allows the COAs to be validated.

The primary method for COA analysis is wargaming, which is a representation and simulation of the environment. Wargaming is useful in visualizing the operation, force strengths, capabilities and potential COAs. It is typically tailored to the specific mission.

Wargaming can be most effective when it has a valid COA, people to make decisions, a fair and unbiased environment, refereeing, consequences of action and be iterative by providing new info as the game is executed.

Wargaming is a complex process and can be used in two different contexts. Outside of COA analysis, it relates to a simulation and training opportunity for battles and wars. In the context of COA analysis, wargaming is the simulation of a particular COA to gain insight for the selected action, and how it may unravel if selected. Wargaming in this context can be broken up further into four steps (Joint Targeting School 2017).

1. Prepare for the wargames
2. Conduct the wargame
3. Evaluate the results
4. Prepare products.

With AI being incorporated, it will need to handle surprises and frequent changes in conditions. Additionally, the AI shall identify where the joint forces are weak, whether the opposing forces know about it, and whether they can do something with that knowledge.

There are currently two types of wargames conducted: manual and computer assisted. Manual wargaming is quicker to implement, while computer-assisted provides some advantages such as being able to readily analyze multiple or blended scenarios (Joint Targeting School 2017).

The results of the wargame are used in the following steps: Comparison, approval, and development. Key takeaways of the wargame are an insight of the weaknesses and strengths of the proposed friendly COAs. If at this point, the commander has decided that a COA is not feasible, they will either discard it and proceed with the others or ask the staff to develop an alternate COA to take its place.

5. COA Comparison

COAs are compared independently and compared against criteria predetermined by the commander. The desired outcome of this process is to realize which COA has the best probability of being successful. Some areas of comparison between the COAs are the differences, advantages and disadvantages, and risks.

6. COA Approval

Once the COAs are presented to the Commander, they may decide to proceed with one or they may instruct the staff to start over. It is common practice for the Commander to make minor adjustments to the COA once they have decided which COA to implement.

7. Plan or Order Development

After the COA has been approved, it is converted into orders, or CONOPS for the forces that will be involved. Besides describing how the joint force shall operate, the CONOPS also outlines the assorted supporting organizations and how will synchronize and integrate to complete the mission. The staff writes the CONOPS in sufficient enough details that subordinate commanders can understand the requirements, tasks, and mission, allowing them to develop their individual plans.

III. NEEDS ANALYSIS

The WRAID team conducted a needs analysis to discuss the overall needs of the system; in other words, why the WRAID system is crucial for today's Naval operational scenarios. The imagined WRAID system was applied to an example scenario, allowing the use of a WRAID-enabled operational battlespace to be compared to a traditional battlespace. As with any system, a stakeholder analysis was completed as it is imperative to define the needs of the system. A requirements analysis of the WRAID system also introduced a brief section of ethical considerations of the use of AI within tactical decision making.

A. STATEMENT OF NEED

With the rapid evolution of today's combat environments due to state-of-the-art technology and high-speed lethal threats, the required reaction time to make combat decisions has significantly reduced. Prioritization of warfare assets, combat units, and combatant requests now depends on an overwhelming amount of information which in turn further complicates human decision making. The number of potential future scenarios in any unique combat situation becomes almost overwhelming for a human to base combat decisions.

In a military combat situation, every second spent deciding on a course of action or countermeasure influences the result. For example, in a naval BLUE ship vs RED aircraft scenario, the amount of time to decide to engage the Close-In Weapon System (CWIS) Phalanx on the RED aircraft will influence whether the counter measure is effective. One second too late and the RED aircraft could potentially fire a missile, causing catastrophic damage to life and property. In another example, the prioritization of tactical assets such as individual combat units, ISR abilities and even logistical supplies can require extremely quick or complex decisions that could alter the success of the mission.

With this ever-increasing complexity, lethality, and pace of warfare, there is an extreme risk of undermining the global prowess of the United States military unless research and development (R&D) is inserted into comprehension and reaction of the military decision-making process.

B. EXAMPLE SCENARIO

An example scenario was presented by retired Captain Scot Miller (email, January 13, 2022) from the Naval Postgraduate School to drive stakeholder identification and operational requirements (Figure 20).

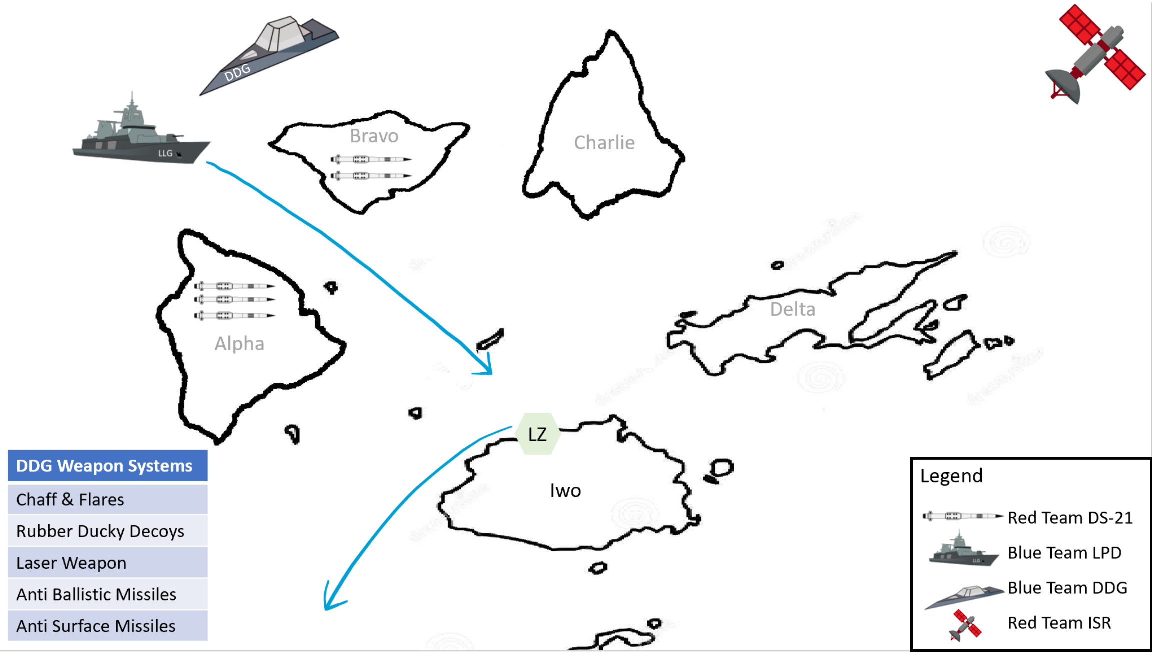


Figure 20. Five Island Scenario

The stage: U.S. uses five islands as possible launch sites for surface-to-surface anti-ship missiles (SSM). RED has suitable intelligence of the five islands and knows the U.S. will likely only use three of them at any one time. The SSM poses a considerable threat to RED.

The mission is to deploy the USMC and their accompanying missiles to Island Iwo covertly. Warfighters are loaded onto a Navy Landing Platform Dock (LPD), and will approach island Iwo covertly at night, with no radiation. A Guided-Missile Destroyer

(DDG), *Oscar Austin* (DDG-79), will provide defensive cover, but is required to keep its distance from the LPD. Covertly inserting Marines on to Island Iwo is a high priority. USS *Oscar Austin* has been told their next mission involves providing defensive support to an attack surface action group, where there will be no time to rearm between missions.

RED believes that the U.S. will be trying to reinforce one of the islands soon and has ISR looking. RED will attack if they detect the LPD or Marines. The LPD itself is essentially defenseless. RED will use decoys, a variety of surface and air to surface anti-ship missiles to attack the LPD if discovered. RED also has shore-based DF-21 ballistic anti-ship missiles, which were designed to be used against a carrier. It is unknown if RED would use them against an LPD. USS *Oscar Austin* also employs a decoy mode, that makes their electronic and hull signature appear more like an LPD, and at night augments their IR signature to appear as an LPD. USS *Austin Oscar* has chaff and flares, rubber ducky decoys, laser weapon, close in weapon system, rolling airframe short range missiles, and three different standard missiles, two for use against a regular surface strike missile, and one that works against ballistic missiles.

USS *Austin Oscar*'s protection mission is complete when Marines are on island. Once offloaded, the LPD will move at best speed into a safer area. Mission planners are in pursuit of significant information to develop a strategy.

- Are there viable COAs that will work to support this mission?
- As more knowledge about RED is acquired, are there amendments to the plan that make sense to change?
- Is there an allocation of missiles that should be assigned for this mission, and a minimum reserve for the next mission?
- If the operators can wargame this in real time, what new insights might that process deliver?

C. STAKEHOLDERS ANALYSIS

As a R&D program and future potential implementation into the Naval Fleet, the list of stakeholders regarding the WRAID system is expansive. A system capability of this scope will encompass stakeholders beginning at the source of military capital thru to the end users (examples are Naval Combatant Commands, Commanders of Naval Strike Groups). Figure 21 illustrates the most relevant stakeholders and their most applicable relationship with the WRAID system. The four domains of involvement include:

- Funding
- Integration and Logistics
- Research and Development
- End Users, or "Owners" of the WRAID system.

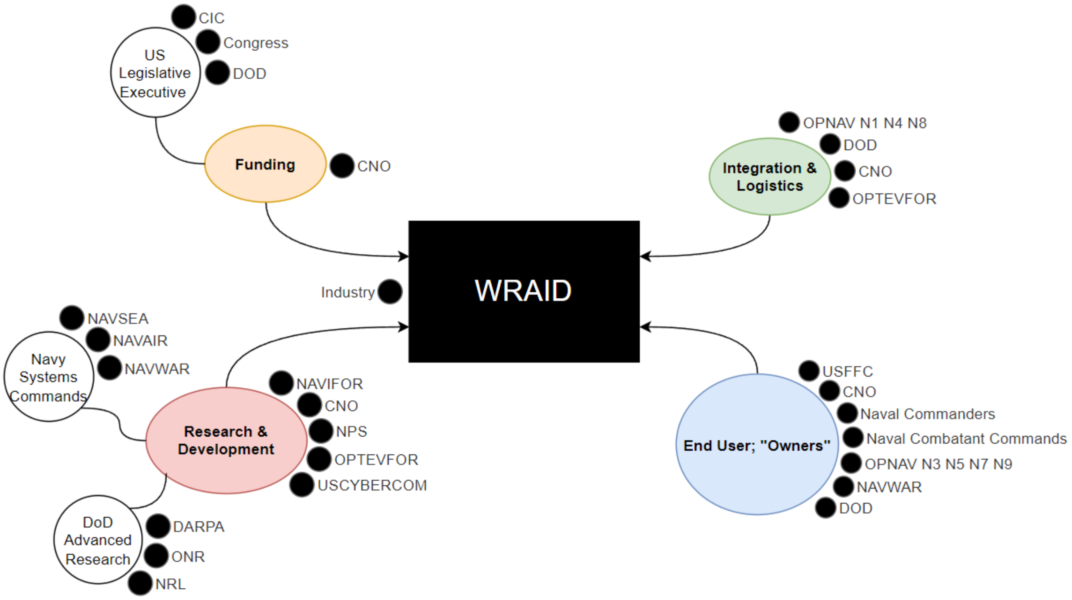


Figure 21. Stakeholder Tree Diagram

Several key stakeholders, most notably the CNO's staff (OPNAV) and the DOD are assumed to be involved with all regards of the WRAID system, due to the nature of it being a DOD R&D project as well as specifically a Naval one. Key organizations within Fleet Forces (i.e., N2, N3, N4.) are more uniquely attributed to subjects of the WRAID system. For example, NAVIDFOR N2 "Intel" and Naval Warfare Development Command are most likely to be involved with the user input to the WRAID system, due to the key inputs needed of the intelligence community as well as overall traditional Naval doctrine and TTP.

The research and development efforts of the WRAID system will encompass most of the advanced research organizations within the DOD, specifically Office of Naval Research (ONR) and the sub organization Naval Research Labs (NRL), as well as the Defense Advanced Research Projects Agency (DARPA). The involvement of these advanced research organizations within the DOD is due to the relative scope and cutting edge of technology the WRAID system exists within.

Depending on the scope of the WRAID system (or comparable similar system) as it enters an official acquisition program, the list of stakeholders is subject to change. The stakeholders included in Figure 21 are those that would be involved in any capacity, small or large, for a true DOD acquisition program of the WRAID or similar system. If the scope of the system narrows, the number of stakeholders would also decrease.

D. REQUIREMENTS ANALYSIS

There are many concepts to consider when exploring potential requirements for a system such as WRAID. As for any DOD acquisition program, the stakeholder requirement list is one of the most important steps to consider. A complete, verifiable, and concise list of requirements ensures the program or system will operate as intended, fitting the need of each stakeholder. To gather stakeholder requirements, subject matter experts within the DOD and Naval community were consulted along with research into prior literature of the subject.

One important consideration is the realm in which this system will operate. Is it envisioned that this will operate at a centralized and global level, or will it operate in the back pocket of every soldier on the battlefield? This decision affects the hardware, software, and network requirements of the system. For the purposes of WRAID in the previous example, it is envisioned that the system will operate at the operational level, where each task force commander and strategic commander will have access. This will allow each commander within the decision making "group" to be keen to the user-inputs to the WRAID system, and the reasoning behind the decision recommendations. The WRAID system will be responsible for the entire operational strike group and the assets assigned to it.

The requirements gathered internally as a team, and externally with reference to prior literature and interviews with DOD subject matter experts are categorized into four sections:

I. Hardware and Software Requirements: Both physical and software requirements of the system. This includes items data collection, supportability requirements, reliability metrics, cybersecurity information assurance requirements, AI training avenues, and computational power maximums.

II. Human-Machine Interfacing Requirements: human-machine teaming interface requirements of the system. This includes items such as data dashboarding, order generation, custom user inputs, and human-machine trust building.

III. Functional Requirements: the capabilities of the system; including how expansive the data input and output shall be required, such as how many assets can be simultaneously tracked or the iteration frequency of the wargaming workflow.

IV. Ethical Requirements: the ethical restraints of the system.

1. Hardware and Software Requirements

The conceptualized WRAID system requires both hardware and software components. Hardware and software have common requirements, including reliability metrics. These requirements are generally quantitative; although the deliverable is only a conceptual architecture of the WRAID system, the reliability requirements of the system are vaguely expressed in Table 3.

Table 3. Hardware and Software Requirements

Requirement Type	Requirement	Units
Hardware	System shall operate at a minimum of XX% full performance with at least X hardware failure(s).	%, Quantity
Hardware	System shall have a minimum mean time between failure (MTBF) of XX in operational environments.	MTBF (hrs.)
Hardware/Software	System shall continue to operate at full performance with a total loss of communications.	%
Hardware/Software	System shall be able to operate with a complete loss of communications for a minimum of XX minutes.	Y/N
Hardware	System shall continue to operate at full performance for a minimum of XX hours with a loss of ship power supply.	Hrs.
Hardware/Software	System should be able to transfer full operations and decision authority to another installation within XX seconds.	Seconds
Hardware/Software	System shall have a system availability metric of ##% (including preventative maintenance, overhauls, repairs, and logistical downtimes) when in intended operational environments.	%

Requirement Type	Requirement	Units
Hardware	System shall be installable on currently available COTS hardware, as well as supportable on COTS hardware to be issued in the future.	Y/N
Hardware/Software	Systems shall be installable on COTS hardware.	Y/N
Hardware/Software	System shall communicate on an encrypted channel.	Y/N
Hardware/Software	System shall be compliant to operate on ship networks.	Y/N
Hardware/Software	System shall be compliant with governing Information Assurance (IA) protocols.	Y/N
Hardware/Software	System shall be installable on current hardware, as well as hardware to be issued in the future.	Y/N
Hardware/Software	Users shall be issued unique logins (Ex: CAC and PIN) with access only to the components and roles they are authorized to view. Access to sensitive data shall only be permitted as necessary for job duties.	Y/N
Hardware/Software	System shall conceal AI/ML algorithms inside a "black box" that cannot be deconstructed by any authorized or unauthorized personnel with access to the system.	Y/N

The hardware and software requirements for the conceptualized WRAID are arguably a living list; these requirements would further be refined as the conceptualized

WRAID system is first physically architected; the hardware and software components would be identified, and requirements would be assigned to them.

2. Human-Machine Interfacing Requirements

The cooperation between the human operator and the conceptualized WRAID system contributes to many requirements by the stakeholders. The WRAID system will be responsible for communicating its operations, recommendations, and orders to the human operator. The interactions between the human operator and the WRAID system are known as human-machine teaming. According to one report, human machine teaming requires three functions to ensure success: observability, predictability, and directability, between the machines (in this case, WRAID) and the humans using it (Johnson et al. 2014). By doing so they overcome the human's natural reluctance to trust the machine's assumptions, operations, and actions.

Investigating further into human-machine teaming to provide an example, DARPA has developed the "ASIST" program, or the Artificial Social Intelligence for Successful Teams. This model proposed by DARPA attempts to create an AI capable of modeling the world and problem-solving scenario the same way humans do by building a similar state-of-mind called "Theory of Mind," or ToM.

Humans can predict future actions based on inferences generated by "their ToM skill to infer the mental states of their teammates from observed actions and context" (Defense Advanced Research Projects Agency [DARPA] 2019). "These models are built on each individual's existing experiences, observations, and beliefs. Within a team setting, humans build shared mental models by aligning around key aspects of their environment, team, and strategies. ToM and shared mental models are key elements of human social intelligence that work together to enable effective human collaboration" (Figure 22) (DARPA 2019, paragraph 3).

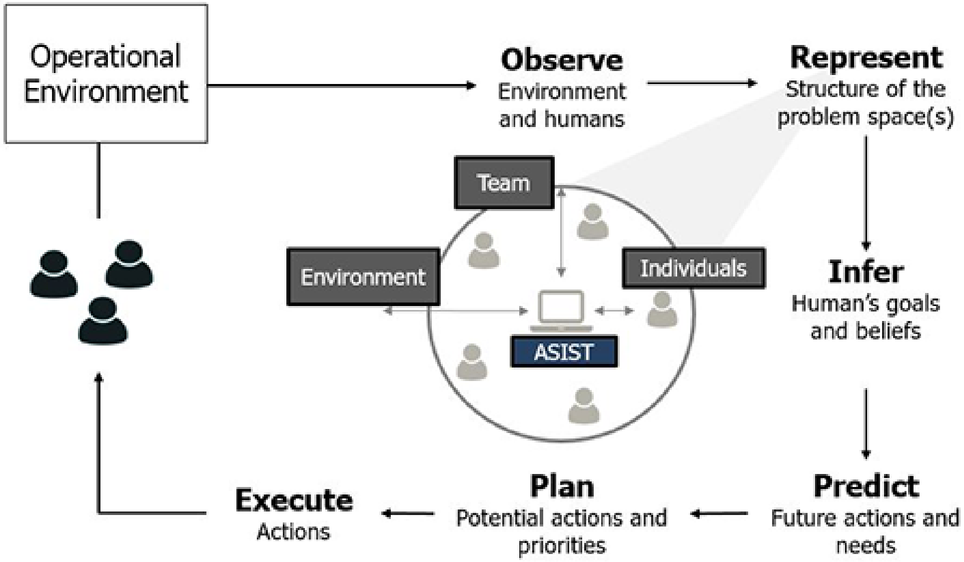


Figure 22. DARPA Human-Machine Teaming Outlining Social Intelligence for Human Teams. Source: DARPA (2019).

For successful integration into tactical decision-making, the WRAID system must successfully establish itself as a useful cooperator amongst the human decision makers. Fundamentally, the human and machine have basic needs between them, as shown in Table 4. Basic flows of needs: mutual observability, predictability, and directability is critical of the human-machine team between the WRAID system and human-decision maker. The easier the flow of information concerning these topics, the more effective the human-machine team will be.

Table 4. Fundamental Human-Machine Teaming Flow. Adapted from Johnson (2015).

Human Informational Needs	Topic	Machine Informational Needs
Machine Actions	Observability	User's Intent
Machine Next Steps	Predictability	User's Expectation/Needs
Human-Machine Language	Directability	User's Communication (Input)

Human-machine teaming requires the ability to eloquently display or communicate the operations, recommendations, and orders of the WRAID system, and of course for the WRAID system to interpret input and ideas from humans. The WRAID system will be primarily built to expand and expedite the mental model and decision-making capabilities of the human operator. To do this, the WRAID system needs to communicate information in a method that is clear, concise, and complete. This can be in terms of screens, virtual reality, or even machine-learning powered human depiction (such as Apple's Siri or Amazon's Alexa agents). For example, U.S. Army researchers investigating how to "thrive in [combat] uncertainty" developed a draft template of how tactical information should be conveyed most effectively (Adamski and Pence 2019). Named the "Multi-Horizon Event Template," mission objectives, enemy decision points, a chronological "roadmap" and simplified graphical representation of the progression of battle are all presented to the user, with a model shown in Figure 23. Figure 24 provides an additional example of a graphical user interface, or "dashboard" presented to the human for their cognizance.

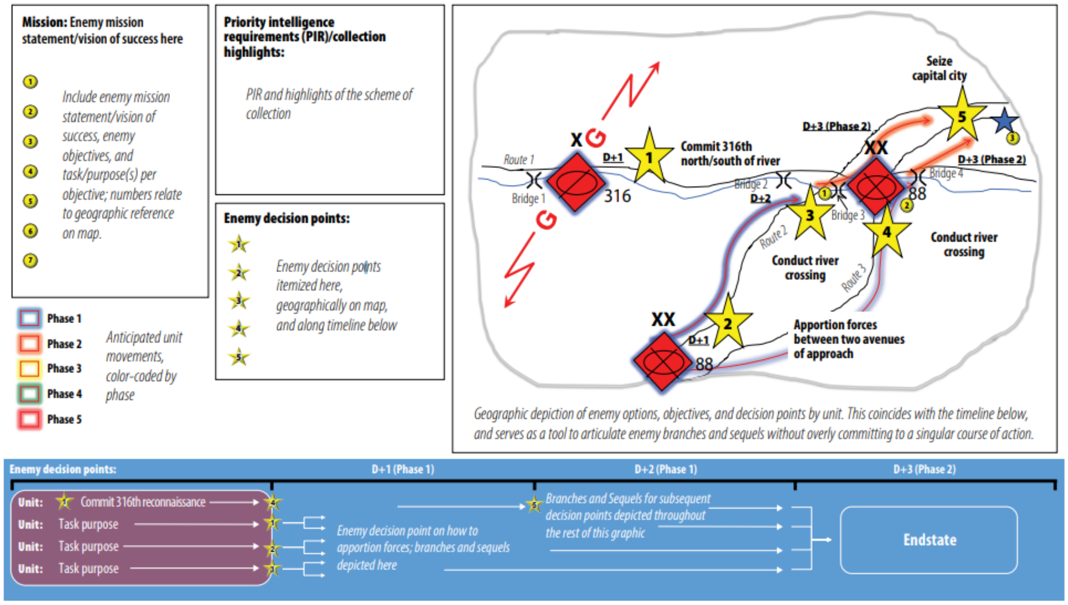


Figure 23. U.S. Army Multi-horizon Event Template. Source: Adamski and Pence (2019).

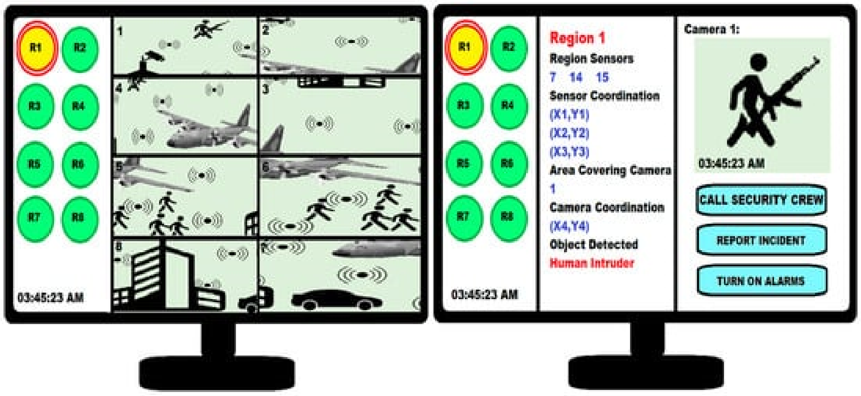


Figure 24. Example User Interface and Data Visualization for Decision Maker. Source: Madni and Madni (2018).

A system that only displays raw data forces the user to analyze and digest that data, incurring additional decision time. WRAID, to the utmost extent possible, should be created to convert all data into information, and present that information with context, which approaches useful and actionable knowledge. The practice of cognitive engineering focuses on achieving these aims.

Table 5 is a list of human-machine interfacing requirements of the conceptualized WRAID system that has been generated.

Table 5. Human-Machine Interfacing Requirements

Requirement Type	Requirement	Units
Human-Machine Interfacing	System shall display information in a user interface contained to a total screen area of # square inch.	Area, Square Inches
Human-Machine Interfacing	System shall display operational information (i.e., current tasks, computing processing, computing statuses, asset tracking.)	Y/N
Human-Machine Interfacing	System shall provide auditory feedback for critical or alarming information.	Y/N
Human-Machine Interfacing	System shall provide touch-screen operation for navigating the user interface.	Y/N
Human-Machine Interfacing	System shall support traditional user input via keyboard and mouse.	Y/N
Human-Machine Interfacing	System shall limit displayed information to minimum (to prevent over-stimulation, obscuring important information).	Y/N
Human-Machine Interfacing	System shall present recommended courses of action in a tabulated format with columns containing statistical confidences.	Y/N
Human-Machine Interfacing	System shall provide explanative reasoning for COA recommendations and wargaming analyses upon user request.	Y/N
Human-Machine Interfacing	System shall allow human operator to input information or preferences as needed.	Y/N

3. Functional Requirements

The functions of the WRAID system, or in other words, the overall goal of the WRAID system are requirements that must be agreed upon by the stakeholders before conceptualization. The functional requirements directly correlate to the scope and magnitude of the program; the more capabilities responsible of the WRAID system, the more expansive in cost and schedule the effort will become. The functional requirements of the conceptualized WRAID system, in accordance with the aforementioned operational scenario, were gathered by involving subject matter experts in the artificial intelligence and war gaming niche within the Naval community, including NPS and Naval Sea Systems Command. See Table 6.

Table 6. Functional Requirements

Requirement Type	Requirement
Functional Requirements	System shall be capable of importing data and associated meta data from all available sources within the operational scenario naval group.
Functional Requirements	System shall be capable of computationally deciphering the naval commander’s intent, adapting the intent to the mission.
Functional Requirements	System shall provide a method for the user to convert the commander’s intent into digitizable objective (for computational purposes by WRAID).
Functional Requirements	System shall be able to receive and be input with ISR data.
Functional Requirements	System shall be able to analyze resources available to create COAs.
Functional Requirements	System shall be able to iteratively wargame the operational scenario at a defined frequency.
Functional Requirements	System shall be able to provide a list of COAs to human operators.
Functional Requirements	System shall be able to provide an order generation list to human operator specific for each COA.
Functional Requirements	System shall iterate the recommended COA list in tandem with the wargaming iteration to provide updated COA.

Requirement Type	Requirement
Functional Requirements	System shall provide statistical confidences for each of the RED team assumptions in the wargaming iterations.
Functional Requirements	System shall be trainable using prior wargaming simulations and historical battles.

4. Ethical Considerations for Requirements

There are also requirements that may change based on ethical decisions and desires. Significant discussion regarding AI and ML is currently taking place, and the decisions made can greatly affect the requirements for a system such as WRAID. See Table 7.

Table 7. Ethical Considerations and Impacts on Requirements

Area of Consideration	Explanation	Potential Effects on Requirements
Human-In-The-Loop (HITL)	In HITL, the AI will make recommendations, but will not take actions or decide without a human operator. This allows the human to check for errors and ensure that the system makes the desired decision. With HITL, the system is used as a decision aid, not a complete solution.	What would happen if the system developed and suggested a COA, and after presenting it to the operator, no action was taken? How long should the system wait for an action? Should the system act, or should it continue to operate? If it were to react, consideration must be made as to what the desired action should be in the event the human side of the interface is inoperable.

Area of Consideration	Explanation	Potential Effects on Requirements
Value of Human Life	Putting a value on a human life is difficult. Even if no explicit dollar amount is assigned, a break-even analysis can be performed (Bardach 2012, 65–66). People put a wide range of values on a human life, impacting the trade-offs when developing and analyzing a COA. For example, if one force values a human life significantly more than another, they may choose to focus on infrastructure and equipment, rather than personnel. Additional care may be taken to avoid human casualties.	During the COA analysis and COA ranking stage, the system will place different weighting based on the value of a human life. Additionally, this value may change depending on the operator and commander, and the system shall be able to adapt to different values. With AI/ML, the system will undoubtedly develop different COAs depending on the values assigned. The system shall also account for if the value for a civilian life versus a military life is different. Relevant information should be presented to the decision maker and human operator.
Bias	When training an AI/ML model, there is always the opportunity for bias or an anomaly in outputs based on prejudiced assumptions made during the development or presented in the training data. In the judicial system, AI has been explored and trialed, but time and time again, it has discriminated against people of color, recommending more severe sentences. Could an AI/ML system discriminate against foreign-sounding names when developing a COA or choosing a target?	Care must be taken throughout the system development and implementation to minimize the potential for bias. Requirements should be developed to minimize or eliminate the potential for bias. But what the requirement would look like or how it would be measured is still a topic of debate.

Area of Consideration	Explanation	Potential Effects on Requirements
Explainability "XAI"	Explainable AI allows the human users to understand the impact and potential biases, leading to better transparency. It leads to a responsible approach, generating greater confidence in the system. While explainable AI has its benefits, there are potential downsides in security. The ability to dissect and reverse engineer the system black box, opens the door to bad actors who may be able to change the system behavior.	Whether to make the system explainable or leave it as a black-box system is beyond the scope of this report. Should experts decide that it should be explainable, this needs to be transformed into requirements, in such a way that it can be measured. It is not feasible to have a requirement that states the system must be explainable because requirements should be agnostic and relatable, regardless of the implementation chosen.

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IV. CONCEPTUAL DESIGN

A conceptual design of the WRAID system was completed by the team. This conceptual design includes discussions on how the WRAID system would fundamentally function, using systems-engineering based diagrams as tools to convey the intentions of WRAID (i.e., black box diagram, activity diagrams, operational and systems-interface diagrams). Key research from academia (including the Naval Postgraduate School) that provides quantitative R&D into machine-learning and AI-enabled wargaming capabilities are included. Lastly, the example scenario previously discussed will be iterated twice: once when using the traditional planning process (also discussed in Chapter II), and the second time using the imagined WRAID system. This provides a segue into future ethical discussion as well as qualitative understanding of the WRAID system using a hypothetical scenario.

A. WRAID SYSTEM PLANNING & DECISION-MAKING

The WRAID system mimics the traditional planning and decision-making process with the key difference being the "brain" behind the process. WRAID leverages AI's ability to perform computations on large datasets without loss of information, while recognizing and minimizing the biasing of data. The same inputs in traditional methods for the planning process are required for WRAID. The decision making ultimately lies with the commander whether the traditional or WRAID process is used. The WRAID system is not designed to supplant the commander, but rather expand the decision maker's mental model to ensure as much information is considered in each decision and COA made. Expanding the mental model of the decision maker is synonymous with:

- Increasing the maximum amount of information or key inputs into a decision.
- Decreasing or negating the effect of human biases on decisions; including cognitive biases (given biases are not introduced into the capability programming).
- Increasing the decision-making speed in contrast to the overwhelming amount of information at which the most efficient and effective decision can be deduced.

This human-machine teaming will ultimately ensure that for any decision made, the most applicable and encompassing information was supporting.

1. WRAID System Description

Reflecting on the Joint Operational traditional planning process as explained in the literature review, incorporating an AI into combat and tactical decision making has the potential to automate and improve much of the decision-making process. Essentially, AI can bring the advantages of speed, efficiency, and effectiveness. The traditional 7-step planning process (as shown in Figure 18) will take on a more simplified form when an AI system is incorporated.

A system of this scope will have many inputs and outputs. Using a traditional black-box diagram (Figure 25), the inputs, outputs, and stakeholder controls can be visualized.

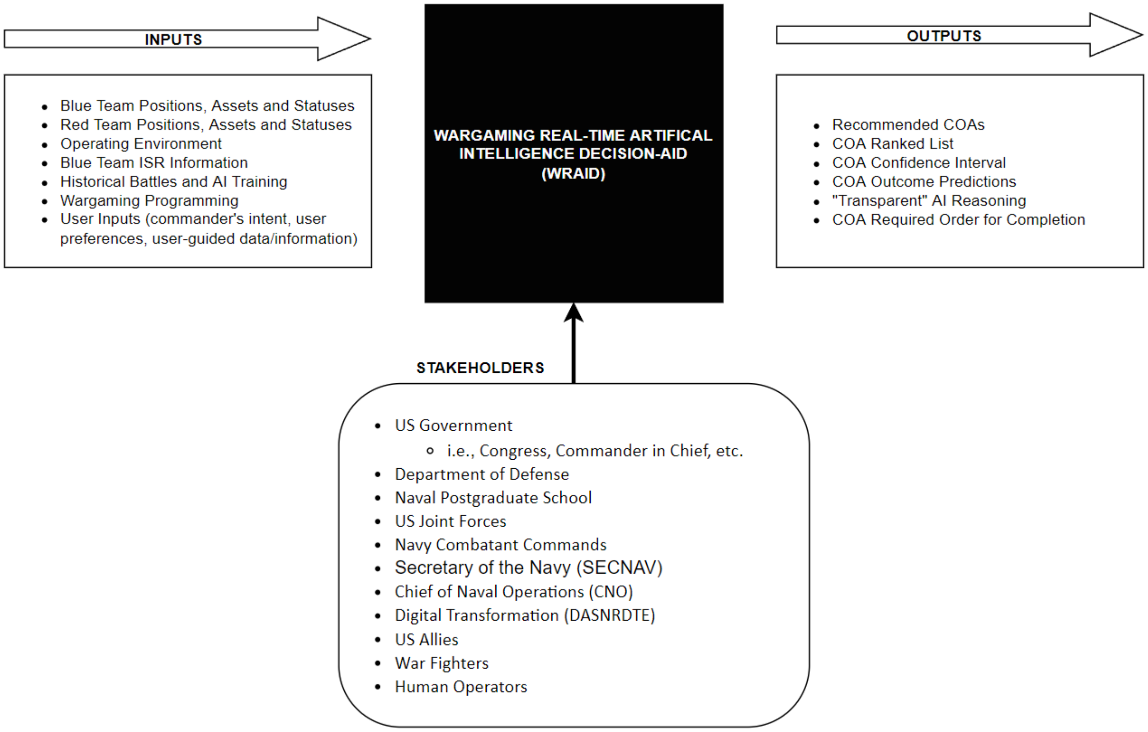

Figure 25. WRAID Black-Box Systems with Inputs, Outputs and Stakeholders

2. Concept of Operations using WRAID for Planning & Decision Making

A high-level operational concept graphic, or OV-1, as shown in Figure 26, can be utilized to translate the black box functional diagram into a visual depiction of the intended operations of the WRAID system.

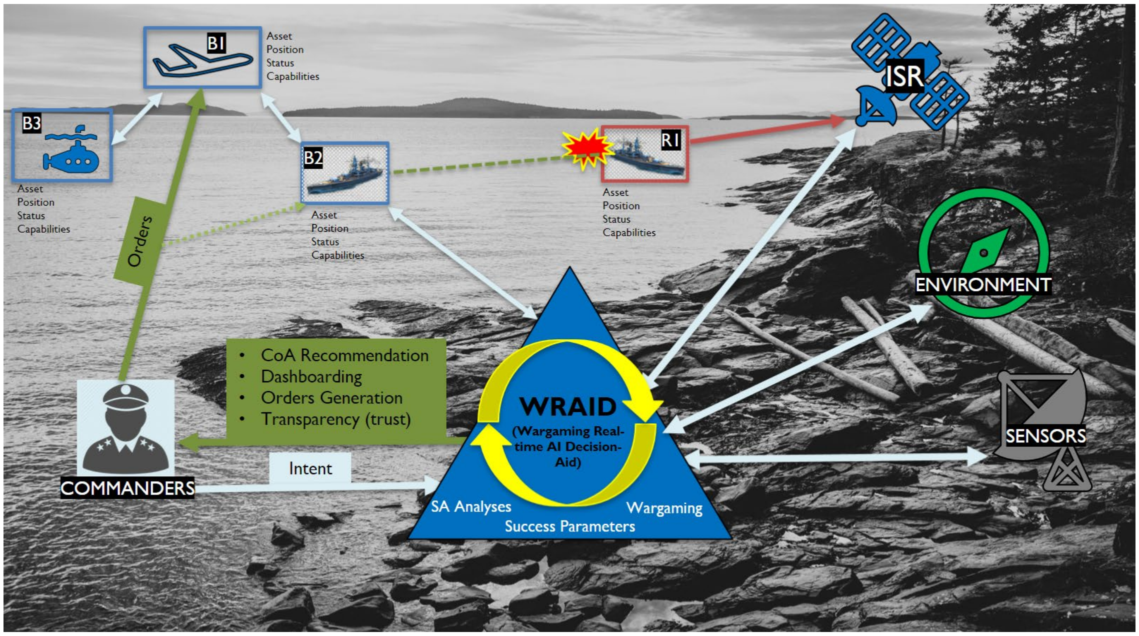

Figure 26. OV-1 Diagram for the WRAID System

The WRAID system will receive input from situational, environmental, and circumstantial sources including BLUE Force's assets (ex. ships, aircraft, and equipped weaponry), any operational ISR information, and all sensors communicating within BLUE force's operational environment. RED Force's assets positions, capabilities (i.e., weaponry, range, endurance, manpower) and status will consequently be obtained. Within the black-box WRAID system, these inputs and the assigned Commander's Intent (i.e., the main objective) will be used to generate respective wargames. These wargames will be used to determine the likely progression of the confrontation. The WRAID system will continue to iterate these wargames on a frequency suitable for the "speed" of the confrontation; this provides an ever-increasing confidence of RED Force intent and ensures the decision recommendations to follow suit. For example, an active skirmish between BLUE and RED force vessels would require an iteration time substantially less than that of one in cease-fire. Courses of action will be generated by the WRAID system and presented in an understandable yet encompassing manner (i.e., "dashboarding") to the staff and decision makers. The COAs presented will have respective likelihood and severity rankings, as well as mission readiness. If the WRAID system generates a COA with an extremely high-risk combination (likelihood/severity) and an urgency for immediate action, the COA will be presented to the users with an alert. As with any human-machine teaming, trust between the human operator and machine must be built. To foster this, the WRAID system will attempt to provide transparent reasoning for each of the COAs it generates. Finally, the decision maker will select their preferred COA and the WRAID system will generate a list of necessary orders to be executed for that specific COA. This process will iterate at an interval determined by the user and the available computational prowess.

Figure 27 depicts a process workflow of the WRAID system. Figure 28 is a Systems Modeling Language (SysML) activity diagram of the WRAID system created in the MBSE software tool *Innoslate.* Figure 29 contrasts with Figure 28, which is a similar SysML activity diagram of the traditional planning and decision-making process. It can be seen using these models, and in Figure 29, that the real-time and iterative process of the WRAID system improves the traditional planning process by allowing modifications based upon immediate stimuli.

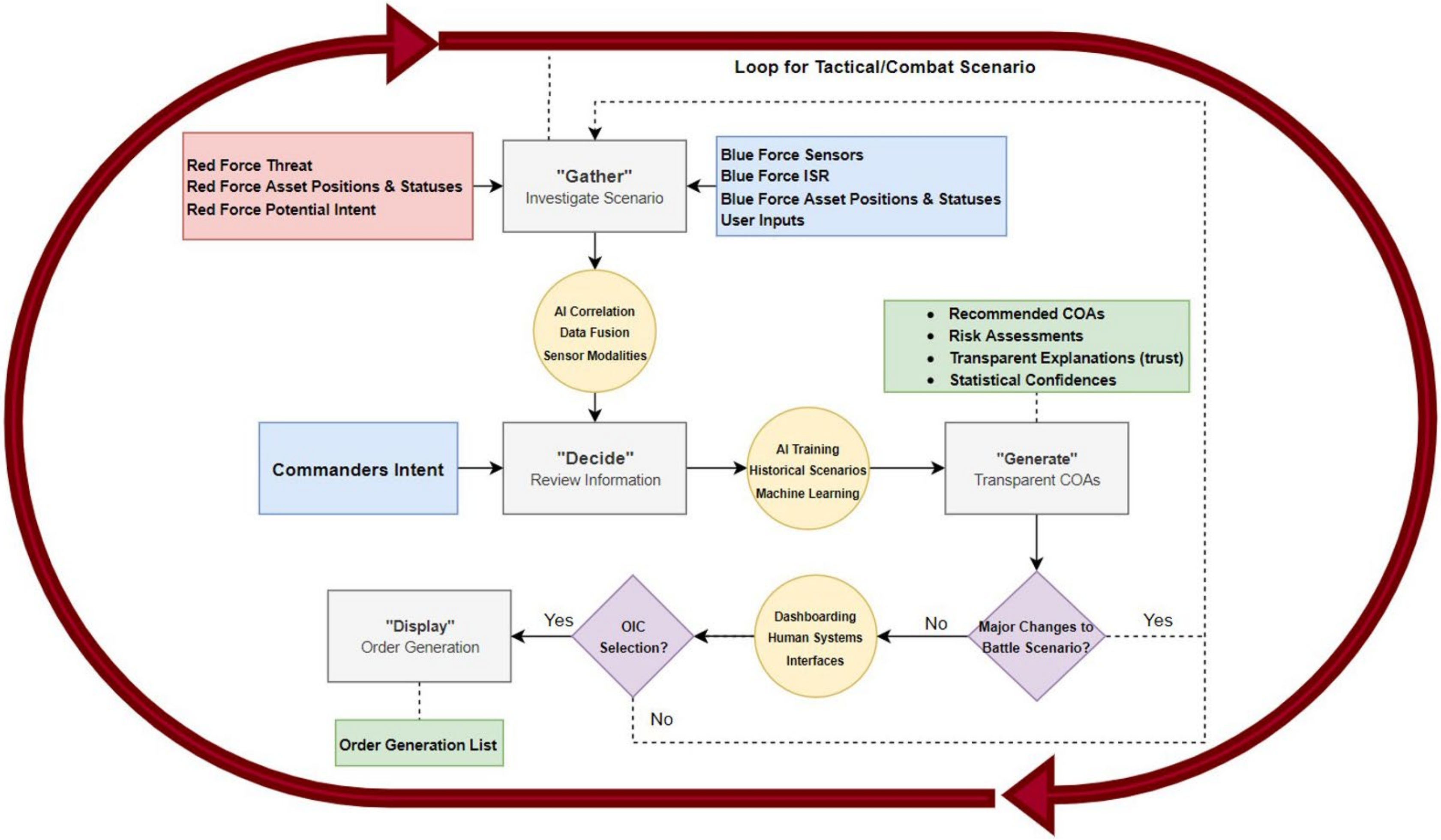

Figure 27. WRAID Planning and Decision-Making Process Workflow

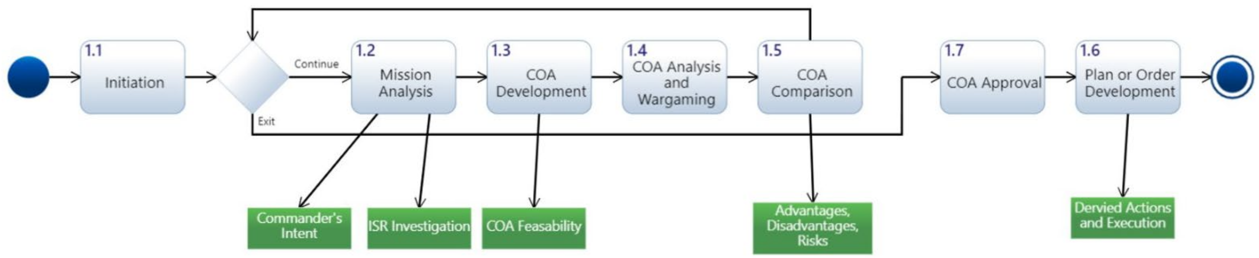

Figure 28. Traditional Planning and Decision-Making Process. Adapted from Joint Targeting School (2017).

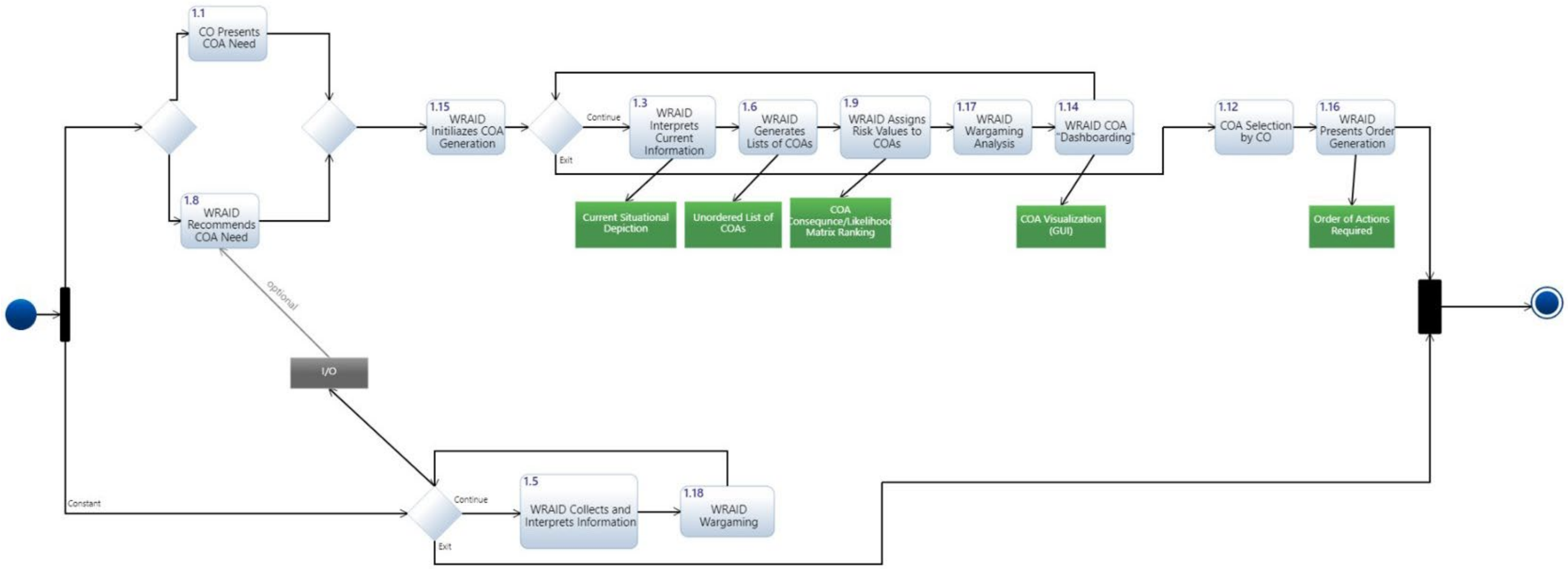

Figure 29. Systems Process Flowchart of the WRAID system

A concise systems-interface description, or SV-1 diagram was constructed to depict the systems, subsystems, and flows between them (Figure 30).

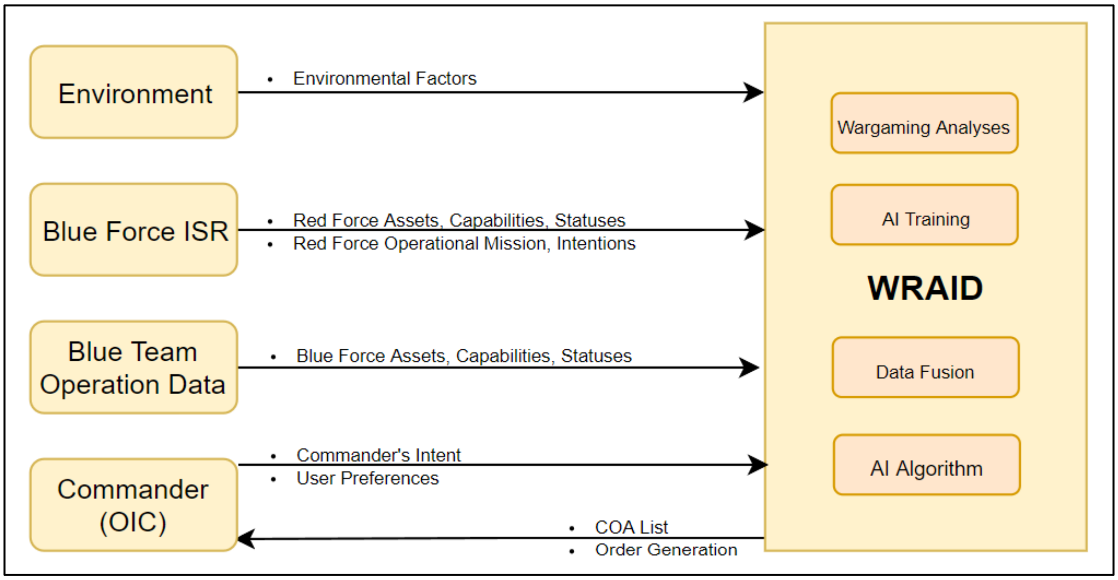

Figure 30. WRAID SV-1 Diagram

3. WRAID Technical Overview

The algorithm within the WRAID system executing all the data fusions, wargaming analyses, and COA generation processes will be designed at the cutting edge of programming and systems engineering disciplines. While we are not yet aware of such an algorithm already existing, we are familiar with several efforts in this general area. The Navy Command and Control Program Office PMW-150 is working on ingesting the various data streams required for our WRAID algorithm. The PMW-150 approach does not automatically generate overarching COAs, it just organizes data. It does suggest COAs for one or two very specific missions. It also does not include wargaming or game theory functions.

One researcher, Bruce Nagy, offered an alternative approach by creating a developmental algorithm that will be able to translate qualitative instructions, such as the

Commander's intent, and return a mathematical model that can be iterated and present suitable courses of action (Nagy 2022). Named "The Automated White Cell and Battle Readiness Evaluation Management" (TAWC-BREM), it remains a work in progress.

This fundamental technique has shaped the design of the "EVE": Event-Verb-Event approach. This is an approach to quantitatively represent the actions and counteractions in a battlespace. Due to an event, a verb must take place, causing the next event. The resulting event is the precursor event for the following EVE chain. The resulting string of EVE chains is a course of action. Within the EVE approach, there are enablers and influencers. Enablers are the "chess pieces" within the game: aircraft, ships, personnel for both BLUE and RED forces. Influencers are other factors, such as the enemy forces, and the environment, that impact the battlespace and allowable verbs. The EVE approach will allow the "playing of chess" between BLUE and RED force in a syntax that can be analyzed and iterated by computer programming, adding machine learning and artificial intelligence into the operational-level decision making process.

While TAWC-BREM is not a prototype for WRAID, the team believes it has several promising applications to WRAID-like systems:

1. TAWC-BREM imagines both a current and historic input, similar to what WRAID will do. However, it is vague on how it intends to convert Commander's intent into digital objectives.
2. TAWC-BREM automates the construction of feasible COAs. However, these are only as good as the assumptions about RED capabilities and intent.
3. TAWC-BREM compares COAs based on wargaming results and interpreted RED Force actions.
4. TAWC-BREM provides causal factors for why certain events occur.
5. TAWC-BREM provides tactical decision and a battle management aid.
6. TAWC-BREM allows the use of both historical and traditional simulated wargaming scenarios as feedstock for algorithm training.

7. TAWC-BREM provides the possibility of creative or “out-of-the-box” solutions to tactical scenarios for the decision maker (emphasis on expanding the decision maker’s mental model of the scenario).

The beginning of the WRAID system largely exists within the data fusion stage. To make any decision, especially within battle, all information, and data available that influences that situation must be known and incorporated into the resulting decision. Gathering the immense quantity of data in an operational space on both BLUE force and RED force is a daunting task. Not only are there abundant sensors on every aircraft or ship within the operational space, each one collects and stores its information in different ways, and with different syntaxes. To collect all this information in a useable way for interpretation by the WRAID system, Godin proposes the use of a “Universal Data Loader” that generalizes the data into the simplest type: a number, integer, or text string. The universal data loader will then categorize and organize the data using associated metadata. As stated by retired Navy Captain Scot Miller (Miller et al. 2021, 5):

> Fortunately, most data are delivered with metadata, that is, a description of the data. For instance, 65 is merely a number, and is useless. But if I tell you that it’s from an Excel spreadsheet, and that the row is named Scot Miller, and the column is labeled age, one can surmise that this author is 65 years old. Similarly, -4.6 means nothing. But if that number is from a formatted sensor read out, that format indicates the name and type of platform that reading was recorded, the location and time of the reading, the altitude of the sensor at the time of the reading, the type of emitter, and the orientation of the sensor to the emitter, well, then I know much more.

Using the organized data with associated metadata, WRAID can populate the enablers and influencers within the operational space.

A broader approach to the issue of data fusion is the executive-mandated standardization of data captured in Naval programs. Currently, the Naval Digital Transformation Office’s goal is to lead, execute and accelerate the overall digital transformation of the Navy, including how data across Naval programs is captured, managed, and accessed.

Another technical discussion for the WRAID system is the method at which the artificial intelligence within the algorithm is trained. Due to the lack of relevant historical data for operational strategies and combat, we must rely on the use of professional wargaming institutions, such as the Naval War College. The Naval War College challenges current and future commanders of the Navy to partake in various types of wargames. These wargames contain the newest in Naval capabilities and strategies and prove more viable than referencing applicable Naval battles from the last World War. If the situations, events, and results of these simulated wargames is captured, the necessary data to train the WRAID system AI may be available. The quality of the training input into the algorithm will directly correlate to the quality of response. A quote from Charles Babbage (~1823), the late English polymath and father of the computer, is relevant:

> On two occasions I have been asked, “Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?” ... I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question. (Babbage 1864, 41)

The last technical discussion regarding the WRAID system is the way in which the information generated by the system (i.e., COAs, order list, statistical confidences) is displayed to the user. As discussed in Chapter III, an effort to effectively, efficiently, and concisely communicate all necessary information to the human operator is critical (Johnson, Bradshaw et al. 2014). The term “dashboarding” has been attributed to the interfaces between the human operator and the information presented by the computer system. A significant amount of both design work and human factors design must be completed in this stage; it is critical to ensure the cooperation between the human and machine is both effective and efficient. Otherwise, there lies potential that the human operator will not trust the system to convey critical information.

B. EXAMPLE SCENARIO

1. Traditional Planning and Decision Making

In traditional planning and decision-making, a plan is created in a linear fashion and reiterated when information changes. The process is done manually which makes change slow. In the scenario presented in the last chapter, the goal is to deploy Marines onto the island Iwo without being noticed by RED defenses on nearby islands.

A traditional plan (Figure 31) would come up with limited likely scenarios and options for the commander and would require a long time to develop. If the scenario changed and intel suggested a sub was in the area and that was not planned for in the likely scenarios the commander has limited options and limited time. The limited options and time would require that the mission be called off with the slow response of traditional planning. Combat situations are always guaranteed to change and preparing for as many changes as possible is invaluable. However, with traditional planning and decision making the scenarios are limited and incomplete or slow to develop.

The following is a hypothetical walkthrough of the scenario.

BLUE Team receives orders to proceed with mission navigating between islands Alpha and Bravo without radiation at night to the landing zone. BLUE Team ISR reports that there are RED Team DS-21 missiles on both islands.

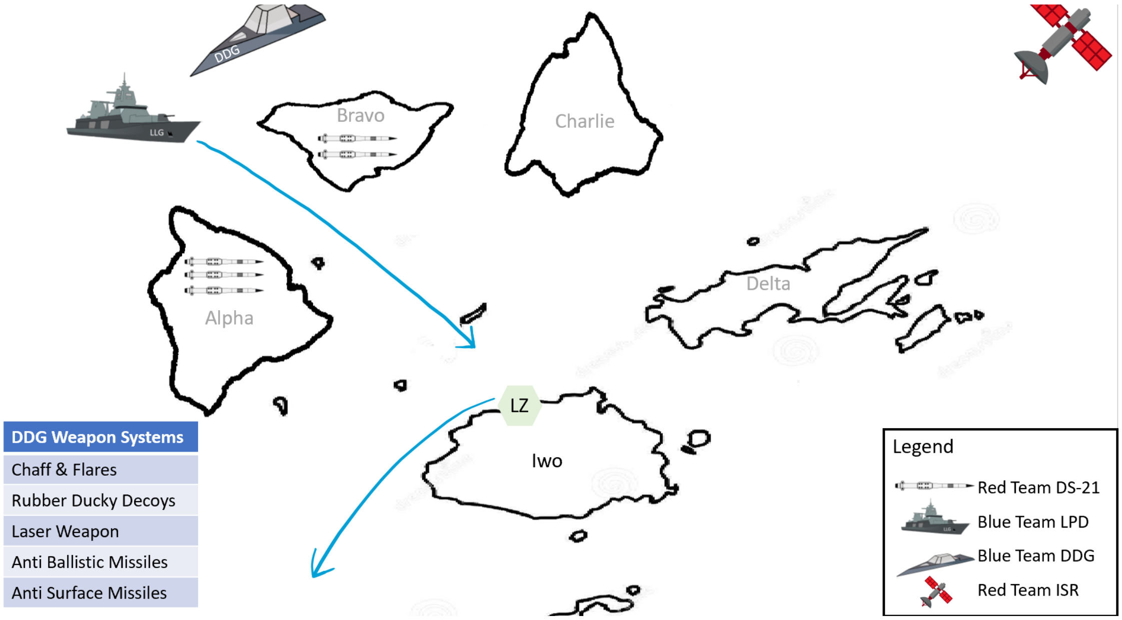

Figure 31. Traditional Planning First Battle Scenario

An updated order is given to the commander to reroute between islands Charlie and Delta to the Landing Zone. The BLUE Team DDG is to follow at a safe distance to provide protection should the mission encounter surprises (Figure 32).

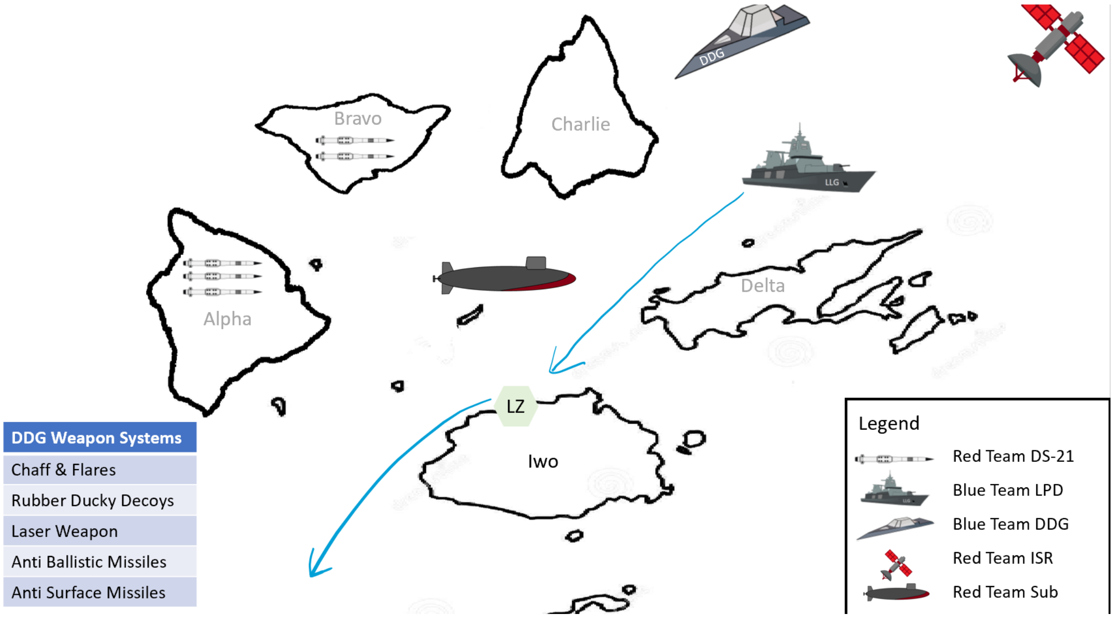

Figure 32. Traditional Planning Second Battle Plan Scenario

BLUE Team ISR now reports that a sub is in the area between the five islands. The commander must either pull the LPD out and abort the mission, or continue with the set plan and attempt to skirt the sub. The planning process is once again executed, and a change of action is selected. Due to time constraints the mission is aborted, and by the time the LPD repositions, and a new landing zone (LZ) is identified, it will be morning and the RED Team will have reinforcements on the way.

2. WRAID-incorporated Planning and Decision Making

The WRAID AI can run simultaneous scenarios with different changes in each of them and offer a best path forward to the commander when the situation inevitably changes. Last minute knowledge of a sub can be one of the simultaneous scenarios WRAID runs, providing an alternative path for the BLUE ship to follow or sending in further military assets in the area. Ultimately the Commander will oversee the decision but with WRAID more actionable options are available and presented.

Leveraging WRAID's ability to run multiple similar scenarios with small changes in variables, coupled with an experienced commander who understands what WRAID outputs are meant to accomplish (expanding the mental model and trade space) will lead to better, quicker decisions, and ultimately additional preparedness. The ability to quickly analyze and pivot to alternate plausible solutions will prove invaluable to military commanders as the battlespace and scenarios continue to become increasingly complex. WRAID's AI architecture must be conveyed so commanders understand what WRAID is, and how to use it to their benefit. As with any disruptive technology there will be a learning curve. However, the realized benefits of a fully developed WRAID system will foster acceptance of, and additional collaboration with WRAID's transparent human-machine teaming.

WRAID presents several possibilities to the commander, once it cycles through the possible variables to establish different plans of attack based on the various scenarios and their likelihood. The WRAID system runs through variables and likely scenarios are outlined:

1. A RED sub/ship in the middle of the five islands.
2. Moving the LZ to the other side of the island.
3. Other islands have more DS-21 missiles than first anticipated.
4. Using the DDG as a decoy to pull the sub from its current location.
5. Several approaches to the island.

WRAID generates five (5) COAs and recommends a plan for the best chance of success (Figure 33). The LPD inserts from the east, between islands Delta and Iwo, with the DDG camped between islands Charlie and Delta ready to engage should an enemy entity appear (a speculation WRAID determined to be highly likely, based on past mission history and wargaming scenarios).

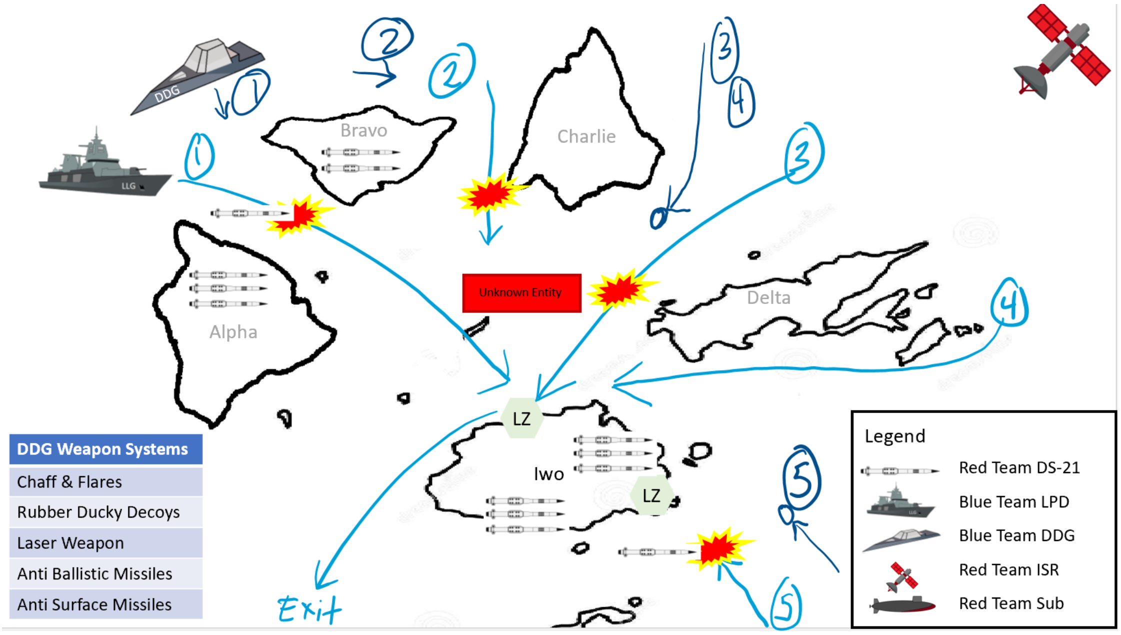

Figure 33. WRAID Battle Plan Scenarios

WRAID provides the commander the opportunity to choose an appropriate and actionable COA in a timely manner, rather than be forced to abort the mission due to repositioning and time constraints. To emphasize, the commander does not have to pick any of the options provided. WRAID is a decision aid tool. The WRAID system will require commanders to be trained on how to use and interpret WRAID results. Understanding how to use the system and training material for commanders will be just a valuable as the WRAID algorithm. The system does not output fixed COAs but rather aids the commander in decision making. Re-running the algorithm with different parameters will yield different results. In this case the potential threat of an enemy vessel in between the islands proves to be valuable input to the commander. This is a simplified scenario; however, it clearly demonstrates the benefits of an AI system integrated in the planning and decision-making process.

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V. WRAID ETHICAL CHALLENGES

The discussion of the use of artificial intelligence is not considered complete until an introduction into the ethical issues is included. Specific to military/defense systems, there are ethical issues introduced that limit the potential capabilities of the system. For example, due to ethical woes following the First World War, the use of chemical weapons was globally banned in warfare following the 1925 Geneva Protocol (United Nations n.d.). However, this has not stopped nations from producing and stockpiling chemical weapons, which is also another topic of ethics. Similarly, the use of small nuclear fission weapons in war is a large ethical concern; due to the fallout radiation causing multiple variations of cancer amongst the Japanese people at the end of World War II, the use of any nuclear weapons was deemed unethical. In fact, the U.S. Army designed, but never fielded, a 20-ton nuclear warhead (shown in Figure 34) to be carried by only 5 men (Seelinger n.d.). It was never deployed as a result of the ban on nuclear weapons in the 1925 Geneva Protocol. Outside of a physical military system, the common order given to U.S. military service members to hold fire until fired upon is an ethical topic in and of itself.

Figure 34. U.S. Army M28/M29 Davy Crockett Nuclear Weapon. Source: Department of the Army (n.d.).

Ethics is not limited to military systems. Groups are experimenting with using AI in the public and private sectors. While exaggerated, the attempts at using AI have proven immature and unready for adoption (Burgess 2020). In one case, an AI-capable system developed for school admissions was rejected by the personnel reviewing it due to induced ethical issues and apparent bias towards minority groups. Developers found there were issues with the data being used by the system. Due to a lack of data to build from, it is more difficult to predict rare events than common events. Commercial systems, especially those on the cutting edge of technology are trail-blazing the path through ethical hurdles. The most relevant example of commercial technologies undergoing ethical battles is the introduction of autonomous, self-driving cars. There are numerous ethics conversations centered about the foremost electrical vehicle auto-manufacturer, Tesla, Inc. Not only does Tesla retrieve usage and user information from the vehicles it produces during its entire lifespan, but the company also leads the charge for self-driving capabilities. In 2019, a fatal accident occurred where a Tesla driver utilizing the self-driving capabilities of their vehicle struck another vehicle. Although the owner of the Tesla argued the vehicle and the parent company was responsible for the accident, the owner was charged with two felony counts of vehicular manslaughter (M. Burke 2022). In a situation where the human is left out of the decision loop (i.e., no human input while driving), can the human be responsible for decisions made by the computer algorithm? In a similar idea, can the manufacturer of a firearm be liable for damages caused by a human wielding their firearm? Would a military commander be liable for damages or war-crimes executed by an artificially intelligent system under their purview?

The consensus of ethics in military systems is ambiguous; there is seldom a unanimous decision. The resulting outlook is a combination of public opinion, likelihood and severity assessments, urgency, and the specific scenario in which the system is applied. In times of war, specific ethical considerations are usually ignored in favor of immediate military response to counter the adversary. For example, in support of the nuclear *Manhattan Project*, a fatally ill patient named Albert Stevens (who later was determined mis-diagnosed) was unknowingly injected with plutonium to study the effects of radiation on the human body (Herken and David 1994). Examples of ethical "hall-passes" during times of war or relative hardship are numerous.

In the U.S. military of today, there are only two unclassified examples of artificially intelligent and/or autonomous acting systems being utilized in the Fleet. The Phalanx Close-In Weapon System (CIWS) is a weapon-system installed on Naval vessels to identify, track, evaluate and neutralize adversarial weapons inbound towards friendly vessels (Naval Sea Systems Command 2021). A similar weapon system Counter-Rocket Artillery Mortar Intercept Weapon System (C-RAM) is the shore-based version of the CIWS and is used to defend U.S. military bases abroad (Figure 35).

Figure 35. Autonomous Afloat and Onshore Weapon Systems.
Phalanx CIWS Weapon System (left). Source: N. Burke (2016).
Phalanx C-RAM Weapon System (right). Source: United States Army Acquisition Support Center (USAASC) (n.d.).

These two systems are unique miltary weapons system; they have the authority to act autonomously, including the firing of weapons. Due to this, numerous ethical considerations are brought forth:

- Who is responsible if the CIWS/C-RAM causes damage to U.S. personnel or native personnel?
- Who is responsible if the CIWS/C-RAM fails to automatically neutralize an adversarial attack that causes U.S. fatalities?

The “who” in these considerations is split between the commander of the facility or vessel, the owner/operator/maintainer of the system, and the original equipment manufacturer. The number of ethical considerations for a defensive system such as the CIWS/C-RAM are miniscule as compared to an offensive weapon, such as fully autonomous unmanned aerial vehicles (UAVs). Autonomous offensive weapon systems provide the possibility of more severe consequences, including the higher likelihood of accidental civilian casualties or even friendly casualties. Allowing an autonomous system to act upon life-threatening scenarios without a human-in-the-loop provides the potential for the wrong decision to be made, given there are other passive options available that a human would have chosen. When an autonomous system calculates a decision, it is done using unique algorithms specific to the system. If the mission is to attack adversaries in a hostile civilian zone, what is the value assigned to the life of a native civilian?

In addition to this brief introduction on the systems ethical considerations of the use of AI enabled military systems, many efforts are ongoing to investigate ethical considerations including researchers Don Brutzman and Curt Blais at the Naval Postgraduate School. Brutzman and Blais have been consolidating discussions revolving around the ethical control of unmanned systems to develop:

> ethically constrained control of unmanned systems and robot missions by human supervisors and warfighters. (Brutzman, Blais, and Wu 2020, 1)

It is important to emphasize that the WRAID system is a decision-aid; it only expands the mental model of the human user. The WRAID system cannot act autonomously, as there is always the required direction of the commander for the final decision. WRAID offers potential RED and BLUE COAs to a commander but does not have the ability to circumvent the commander and give an order. The WRAID system uses the strength of a computer’s processing power and combines with the understanding and experience of the decision maker. Many of the challenges with AI are assigning the worth of a human life, while the cost of a naval warship is known the cost of a sailor can be difficult to weigh. AI can place unbalanced weight on human life, both too low (win at all costs) or too high (be too conservative). The key to avoiding these unbalanced weights is transparency in how the AI came to that conclusion and ultimately placing the commander in the decision seat.

A. EXAMPLE SCENARIO ETHICS

In the previous two chapters a scenario was used to explain the benefits of WRAID. This section will discuss the ethical concerns with using AI in the previously described scenario. The commander has an important task when inputting parameters, not only for the successful generation of this scenario but also potential spiral effects of future mission inputs.

Input parameters can create AI bias, either intentionally or unintentionally, which will affect the output of the WRAID System. The concern with this is that the WRAID system would fail to expand the mental model of the commander or expand it in non-optimal ways. If the inputs of commanders are also used by the WRAID system to add to the database used to make future decisions, then commanders could "poison the well" and affect future outputs of the WRAID system.

There is a cognitive bias that may lead to a predilection for the commander to select one of the five COAs WRAID developed rather than treating WRAID as a tool to expand mental model. The commander does not have five options in this scenario. WRAID only developed five, although there are numerous ways to respond to any situation. The risk of affecting and leading what commanders will do based solely off one program can be dangerous even in one as advanced as a WRAID system.

The WRAID system has direct implications on BLUE troops. The value placed on human life is a hard reality of war. Over-value a human life and you can severely handicap options available to you and risk failing missions. Conversely, under valuing human life can lead to riskier COAs and deadlier options; "winning but at what cost?" The value of human life needs to be well balanced, and that balance needs to be discussed and found. In the scenario undervaluing the BLUE troops can lead to choosing to overwhelm the RED troops with sheer numbers. Over valuing could lead the WRAID system to output a COA stating to take no action at all. The value of human life also plays a role for RED troops. It is the goal to eliminate as many RED troops as possible or to remove the leader. This can change how WRAID will respond with a precision attack (e.g., when the Navy Seals eliminated Bin Laden), or with a more classical military approach.

The ethical implications on AI in military applications is a concern that will not go away and require ongoing discussion. Walking through or gaming military scenarios provides increased benefits and understanding about the ethical implications of using AI assisted systems, such as WRAID. This scenario is simple yet effective and developing more COAs with new starting parameters can show how big an impact AI ethics has.

B. SUMMARY

In summary, the WRAID system is conceptually designed to mimic but improve upon the traditional planning and decision-making process. WRAID leverages AI's ability to perform computations on large datasets without loss of information, while recognizing and minimizing the biasing of data. The WRAID system is intended to expand the user's mental model to ensure the maximum amount of information is considered in each COA and decision. As depicted in the example scenario, WRAID enables increased decision speed, as well as various and iterative COA options. WRAID, and similar AI systems, will face not only considerable organizational and engineering challenges, but also ethical challenges that will delay this type of technology progressing from theoretical to a fully deployed realization.

VI. CONCLUSIONS AND RECOMMENDATIONS

This research aimed to investigate and explore the opportunities to leverage emerging AI and other computing techniques to reinvent the Navy's approach to planning and execution. What was revealed are significant new possible capabilities to expand the mental decision-making framework of Commander's and their staff in ways that decrease the decision cycle while taking advantage of much more already available data and information. Due to ongoing defense research, it now seems possible to invent an entire calculus based on courses of action, and apply algorithms, game theory, war gaming, and other simulations to rapidly identify "best" COAs. However, difficult challenges remain. The entire DOD has a poor data sharing culture, which stymies data collaboration. Classification clouds the data ingest and use processes. AI training data sets demand new after deployment curation, and staid SE processes might not adequately address all the engineering needs for AI assisted systems. Finally, the ethical use of AI and autonomy raises many questions, most of which are unanswered yet.

The final chapter of this report encompasses the conclusions derived after researching and discussing topics concerning the WRAID system, or any representation of a WRAID system that uses AI to revitalize military decision making. A brief section of the results and findings contains the most notable information found within the research effort. A section to proclaim benefits to the U.S. Navy is included to persuade Navy research sponsors to continue pursuit of AI-enabled wargaming decision aids. A substantial section on the roadblocks encountered during the research, and to be encountered during the development of a WRAID-like system is also included; this is directly followed by a series of recommendations to help counter those obstacles. Lastly, areas/topics of future research are recommended by the WRAID team.

A. DISCUSSION OF RESULTS AND FINDINGS

The WRAID report originated based upon the demand for investigation into the use of AI into today's Naval tactical wargaming and decision-making processes. Through a traditional system engineering approach, discussions with relevant academia and defense research institutions, and experiences related to our individual careers, the feasibility of the WRAID system was developed. This report has organized the beginning of:

1. …the system requirements and stakeholder collection concerning WRAID or WRAID-like system.
2. …a fundamental conceptual design of WRAID or WRAID-like system.
3. …the imminent obstacles preventing the development and usage of WRAID or WRAID-like system, including ethical considerations.

The requirements for WRAID or WRAID-like system were separated into three categories: hardware/software, human-interfacing, and ethical considerations. Within these three categories, personal education, experiences, and subject matter expert opinions on requirements of the WRAID system were placed. Traditional hardware and software requirements that exist for most, if not all, DOD acquisition programs were generated (ex. DOD cyber information assurance policies). With a system that has great influence over the military decision-making process, a specific robustness and security is required, as detailed in the requirements listed previously. Human-machine interfacing is a large component of the WRAID system; it is inevitable upon diving into research into artificial intelligence that humans do not trust or emphasize something he/she cannot understand. If the WRAID system is to provide courses of action to the commander, it is imperative that the WRAID system be able to eloquently but concisely explain how the COA recommendation was made. Ethical considerations, as opposed to requirements, were listed to begin the discussion on ethical hurdles an AI in tactical decision-making will encounter. This list, along with the other requirements lists, are not complete; more than a few unforeseen requirements will be encountered during every step of the acquisition program; especially during the preliminary stakeholder analysis and R&D phases.

The conceptual design of the WRAID system provided systems engineering diagrams and analyses suited to the development of the system. The black-box and operational (OV-1) diagrams provide a high-level view of the WRAID system's intended outputs given specific inputs, allowing later adopters to have a common understanding of the intended resulting system. WRAID also requires a quantitative research/engineering effort that can potentially support the internal algorithm within the WRAID system, the "black box." One leading example is TAWC-BREM since it introduces ways to mathematically represent and iterate courses of action throughout a tactical scenario. This type of research is fundamental to the WRAID system, as the algorithm is the backbone of any AI-enabled system.

During the research the team encountered topics that are substantial roadblocks to the WRAID system. These roadblocks include data availability, DOD program office culture, suitable avenues for algorithm and machine-learning training, and systems engineering limitations. These roadblocks stem from high-level organizational policies and cultures that hinder the development of cross-organizational/cross-platform/cross-program systems. "Top-down" changes must take place to remove these roadblocks, which prevent large AI-enabled systems from being developed. Solutions are offered later in this chapter.

B. BENEFITS TO THE NAVY

The DOD is increasingly exploring AI for new capabilities and strategic advantages in today's battle landscape. Staying ahead of foreign powers in the development of AI will ensure that a competitive lead is maintained (Vincent 2017). AI can greatly enhance the U.S. warfighting capability and lethality, as well as conflict mitigation.

The Capstone report results will benefit the United States military and intelligence communities. For the military communities, primarily including the Naval community, the results of the study may be incorporated into actual research and development projects for feasibility studies. For intelligence communities, the awareness of how a conceptual real-time AI wargaming capability is currently envisioned is important for future preparedness. The Chief of Naval Operations and the other joint services will benefit from the examples set in data collecting and reporting efforts that are inevitably required for WRAID-like systems.

The primary outcome of the real-time AI wargaming decision-aid capability study is the preliminary conceptual architecture and design of the capability; this includes ideas into how the AI will be trained, how the AI will receive information, and how the AI will operate to expand the mental model of the human decision maker. This primary outcome also contains an imagined real-time AI wargaming decision-aid capability, which in a generalization will apply to nearly all the United States military and intelligence organizations. Discussion of potential requirements will provide a path for future discussion on the development of a system like WRAID. The research and development contained within this study will mostly benefit the DOD and our warfighters, as the proposed capability will give the warfighter a significant advantage over the United States' adversaries.

The secondary outcome of the WRAID capability study is the discussion of ethics regarding AI, and the discussion on the ethical implementation of a militarized AI. The ethical implications or considerations of a capability that will effectively recommend military courses of action have the possibility of being severe. A study into the ethics of an AI wargaming decision-aid was completed to help describe and expose the most essential concerns. The benefits of an ethics discussion predominately benefit the United States DOD. As primary "owner" of the imagined real-time AI wargaming decision-aid capability, the ethical concerns that will arise during the development, testing, fielding, and operation of the capability will have to be answered by the United States DOD, such that the capability may be justified. Ethical decisions will undoubtedly impact the system requirements.

C. ROADBLOCKS

Several roadblocks will impede the realization of the WRAID system. It may be surprising to discover that algorithm development (i.e., the "brain" of the system) is not the long pole in the tent. The majority of the hinderances WRAID, and other advanced AI systems, will face is data, compounded with various stipulations.

1. Data Fusion

"Derived from the recommendations of the U.S. Department of Defense Joint Directors of Laboratories Data Fusion Subpanel, namely, data fusion is a multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats and their significance" (Klein 2004, 2). This allows for the creation of multi-dimensional viewpoints of a situation through the integration of various data streams producing information that is routinely more consistent, accurate and beneficial than any singular data stream is capable of (Davis 2022).

In layman's terms each of the various incoming data streams provide a slightly different vantage point of the emerging situation. Consider two-dimensional (2D) shapes versus three-dimensional (3D) forms as depicted in Figure 36. The additional dimensional view provides supplementary details, and information not present in the 2D visual, without which we would not be able to determine the actual shape of the object. If the sensors and data provide only a two-dimensional view or rendering of an object, such as the 2D circle or disc in Figure 36, we only have part of the information, part of the puzzle. By adding an additional vantage point, pertinent and necessary information about the object is gained, as well as the ability to more accurately determine if the object is a threat and what possible counter actions we have at our disposal. This translates to the WRAID system exponentially, where we are no longer concerned with adding one or a few dimensions or vantage points, but now we are adding thousands, if not hundreds of thousands (or more) additional vantage points/data streams. Each of which adds another layer of relevant and necessary informational nuance, facilitating the definition and refinement of the battle space.

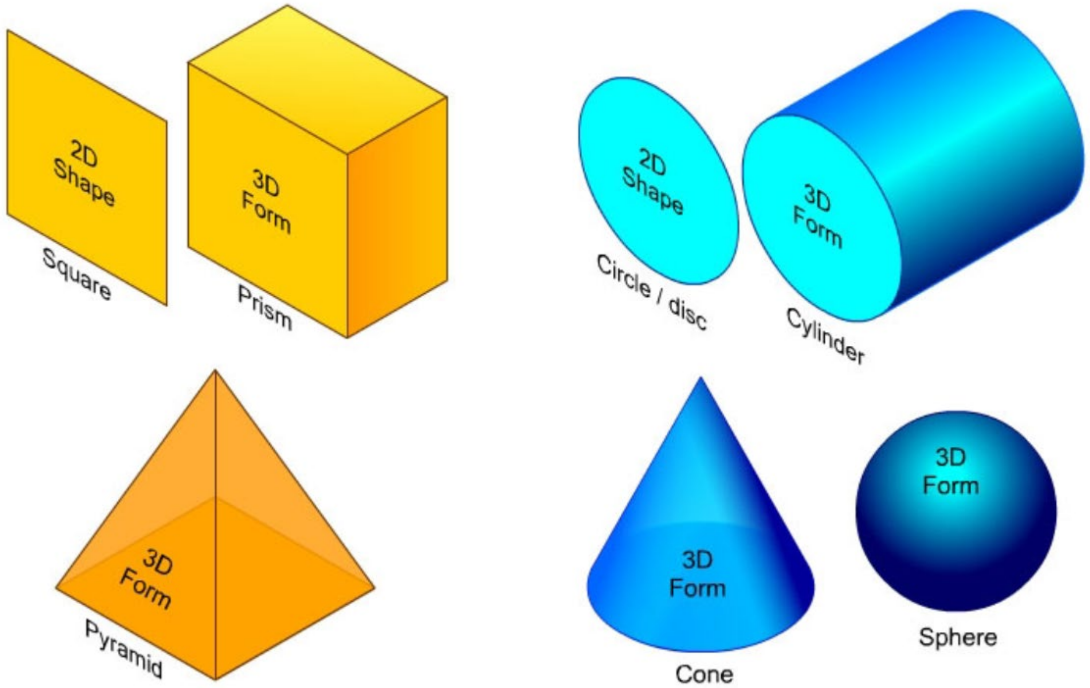


Figure 36. Two-Dimensional Shapes vs. Three-Dimensional Forms. Source: Lipot (n.d.).

The idea of tens of thousands of data streams all being collected and merged to describe and assess the battle theater and situation is paramount to the realization of a fully functional WRAID system. While there are several processes and methods for realizing data fusion, the real concern is the logistics of the data. The litany of data streams needed to train and recursively feed an AI of this type is staggering to consider. The coordination and assimilation of an innumerable set of data streams across multiple service branches, DOD components and varied U.S. allies into a single format or tool for analysis is an expansive undertaking. This is all without mentioning the imperative, but equally daunting tasks of data grooming, cultivating, curating, securing, and farming.

2. Programmatic Constraints

As WRAID is a proposed military system, the potential pitfalls and constraints associated with DOD culture, systems, data, classification, and distribution warrant discussion. “Gathering suitable data for defense application has the additional challenges of handling classified datasets, and ensuring data is secure and protected from cyberattacks” (Johnson 2021, 11). To realize necessary capabilities, different DOD components, groups and military branches fund and oversee the life cycle of new products which provide the capabilities. This facilitates compartmentalization which aids in maintaining classification levels and the security of sensitive, secret, and top-secret information. However, this also continues to promote the current culture of compartmentalization rather than collaboration. In a world on the precipice of AI, full compartmentalization becomes a hinderance. To continue expanding the advantage, and enable the next steps in cutting edge defense, the data collected and maintained needs to be standardized, and systematically applied to every program. Data collection and grooming need to have specific requirements that apply to every U.S. military branch. This is a systemic issue requiring operational intervention to correct effectively. As it stands now, specific data requirements are determined on a program-by-program basis with no standardization of data collection and grooming requirements, format requirements, retrieval capabilities, or centralized data storage (specifically for collaborative efforts such as AI training, and joint tasking). Comparatively, this is the Wild West; data, if collected, is not often maintained, and even if it is, it is not in an easily accessible form.

3. AI Training

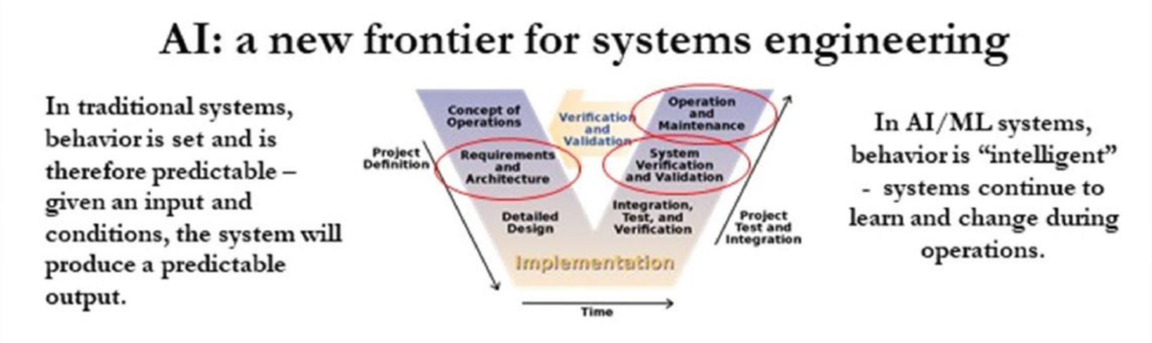
Two primary challenges have been observed in training AI: Lack of training data and training induced bias. Collecting data with modern capabilities, tactics and environments is not an easy task. Realistically speaking, the only way to obtain real data, capable of training WRAID’s AI algorithms on modern warfare is to go to war, in earnest. Data is not worth the cost of war, which brings us to the next best thing, mathematical models. Wargaming data is collected, groomed, and fed to WRAID’s internal algorithms.

Another substantial challenge of training any AI is eliminating or reducing the induced bias in the system. Commercial systems that have been previously developed have shown bias in their decision making (Burgess 2020). In one instance, an AI-enabled system was developed that predicted whether a knife or a firearm would be used in an individual’s first violent crime (Burgess 2020). This system was recognized for being biased because it was heavily reliant on age and criminal history as a factor. Young adults, according to the system, were more likely to commit a crime. Additionally, criminal history can also be biased since responding officers create bias in the source data when deciding whether to arrest an individual.

Modern wars and battles have had strong diplomatic and non-combat components. In very recent history, the Ukraine invasion involving Russia had significant diplomatic actions and involvements. WRAID is designed for the operational and tactical level of war. There will certainly be aspects that are beyond the scope of what the AI system would be able to consider and recommend, including deterrence by world powers, controllability of other systems, and crisis instability (Wong et al. 2020).

4. Systems Engineering Limitations

Emerging AI and connected systems are ushering in a "new frontier" in systems engineering (Figure 37). Current systems engineering methodology applies to complex systems with predictable and programmed outcomes. With the incorporation of AI, we are no longer living with specifically repeatable outcomes.



AI: a new frontier for systems engineering

In traditional systems, behavior is set and is therefore predictable – given an input and conditions, the system will produce a predictable output.

In AI/ML systems, behavior is "intelligent" - systems continue to learn and change during operations.

Figure 37. Artificial Intelligence: A New Frontier for Systems Engineering. Source: Johnson (2021).

The systems engineering process must grow to encompass the unique challenges of AI enabled systems. Specifically, we must account for the requirements of learning systems: how to effectively validate non-deterministic and evolving results throughout the AI life-cycle—how to handle unforeseen failure modes and root cause tracing that is difficult to discern; and, how to ensure AI systems are transparent, trustworthy, and robust, providing the ability to adapt over the life cycle (Figure 38).

Figure 38. Challenges in the Engineering of Artificial Intelligence Systems. Source: Robinson (2021).

D. RECOMMENDATIONS

The team has identified several recommendations for the stakeholders regarding the use of AI in the military decision-making process.

1. Systems Engineering

Systems engineering plays a vital role in the acquisition process throughout the life cycle of a system. Applying suitable systems engineering techniques and forms of workflow can decrease costs and ensure a higher level of effectiveness. Systems Engineering ensures the right system is built and the system is built right. A 2012 study concluded that System Engineers have a significant impact on project performance (Elm and Goldenson 2012). Figure 39 shows a comparison of project performance to total systems engineering capability (SEC). As the systems engineering capability increases, so does the project performance.

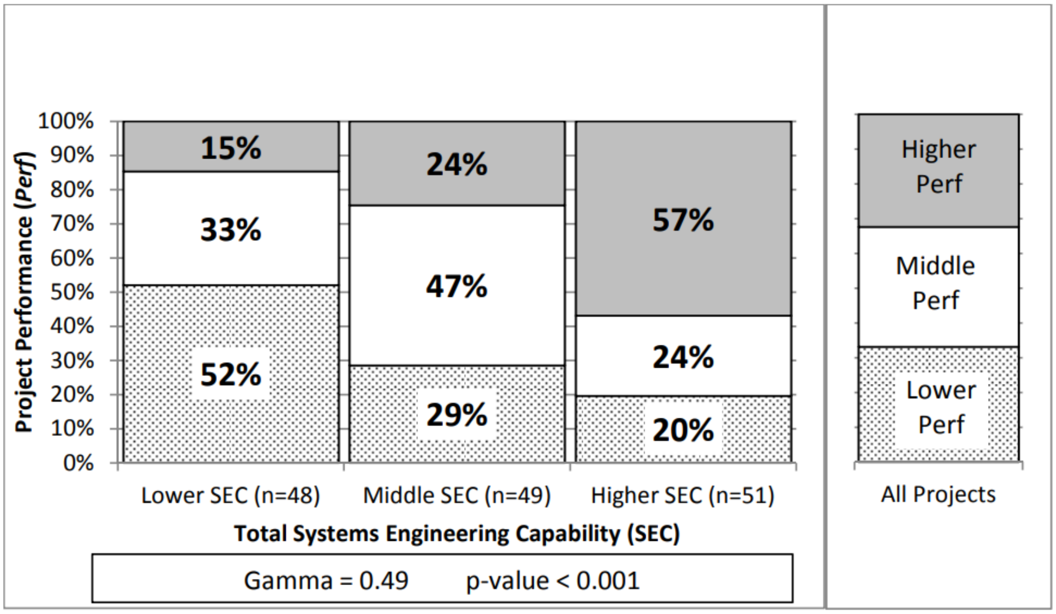


Figure 39. Comparison of Project Performance to Systems Engineering Capability. Source: Elm and Goldenson (2021).

The efforts and actions we perform with systems engineering need to be expanded to account for AI enabled systems. This technology is not about to go away, a substantial government and industry led operational effort to restructure the systems engineering enterprise is necessary, not only to work with AI now, but to grow and thrive with it.

2. Data Capture and Availability

To train any machine-learning algorithm, suitable and sizeable data is required. In this specific example, the WRAID system would require quantitative data on the following topics:

- BLUE Force assets and capabilities
- RED Force assets and capabilities
- BLUE Force intelligence, surveillance, and reconnaissance streams
- BLUE Force simulated wargame scenarios and results
- Environmental conditions

To begin, the data must be captured with the appropriate level of accuracy and reliability for the WRAID system. Once the data is captured, it would be beneficial to have a standardized method of data organization across all sources of data. After it is captured, the WRAID algorithm, which was initially iterated using the simulated wargame results, would apply the specific scenario to the historical data.

Currently, data for BLUE force assets and capabilities are not being collected and stored in a common manner that would allow for a system such as WRAID to be developed. Naval program offices and DOD ISR organizations are not collecting and reporting standardized data streams to Naval commands for use in Fleet-wide systems; this must change if a machine-learning system such as WRAID is to be developed. The effort to require data collection and reporting requirements will ideally come from "top-down," as mandated by CNO policies into the program offices.

It is recommended that efforts to design, develop and deploy the emerging Navy Central Artificial Intelligence Library (CAIL) concept continue. CAIL is envisioned to be the central organization responsible for enabling the access to validated and secure naval AI/ML data. Drawing on Robert French's research (French et al. 2021), Dr. Bonnie Johnson contends that CAIL will also serve as the "data management system and process for identifying data sets and providing indexing, validation, auditing, and secure access" (Johnson 2021, 8) to data resources for naval AI/ML applications.

3. Collaboration

Throughout the research for this project, the team has identified several domestic groups already developing some form of AI for use in the wargaming and decision-making realm. While these projects vary in complexity and usefulness, they still provide an avenue for information sharing and lessons learned. These avenues of increased awareness would be mutually beneficial to all parties involved. One such project is the Marine Corps' Athena.

Athena is a wargaming tool that was developed to evaluate the future AI applications through the education and testing of such a system (Jensen, Cuomo, and Whyte 2018). The platform is like an Amazon Alexa device, in which decision makers are able to ask questions and get information from the Athena device. The system is used to collect information currently, such as what bits of data the planning team are using. There is a lack of information and data that can be used to develop and train an effective AI. Athena aims to provide a better educational environment for the warfighters, provide a testbed for new AI applications and serve as an automated red-team. With enough data, it is hoped that Athena will be able to learn and simulate modern operations.

4. Breaking the Culture Barriers

There is resistance within the armed forces to embracing new technology. This is neither new nor unique to the United States armed forces. Despite the printing press revolutionizing the printing of books and documents, for nearly 400 years, the Ottoman Empire did not allow the Koran to be printed (Juma 2016). It is believed that this was done to preserve political power and to protect self-interests and livelihoods. If the Koran could be printed, then what were the calligraphers and scribes to do?

America's military is very reliant on old technology, and in many cases, would rather make incremental improvements to make the system work rather than explore new technology. There are multiple efforts to break the "*this is how we have always done it*" mindset that is prevalent in the current military/government culture, however as with early systems engineering and program management efforts, this can take time to drive change in the workplace. This encompasses using old, broken technology, things that do not work as intended and fostering an environment of division rather than collaboration. These outdated ideologies need to be eradicated organizationally, as they are a clear barrier to moving forward and expanding the advantage.

5. Determine AI Ethics Early

As discussed previously, ethical considerations will have a profound impact on the system. These decisions are best left to the stakeholders as well as ethics experts. Integrating the requirements and acknowledging the concerns early in the design process will enable integrators and designers to incorporate it from the outset and ensure buy-in from all stakeholders, rather than leaving it as an afterthought.

6. Simulations and Data

Simulations will be key in refining the system requirements and setting realistic expectations. Spending time conducting simulations will allow for more effective systems development and identify weaknesses and gaps in knowledge.

For example, the team has identified several issues with data, including collection and handling. Artificial Intelligence has extensive capabilities, but it is not magic. Data processing typically needs to be in a specific format for processing to occur. In image recognition, this usually means the photo must be rasterized. It is envisioned that a system such as WRAID will need to incorporate data in a wide variety of formats and encryptions. Standardizing the data format will allow for better integration and more rapid deployment. Data format will likely affect system requirements, both for a system such as WRAID and any other systems that it must interact with. Developing these requirements early will prevent headaches and cost increases down the road.

Many large defense contractors have been working with AI/ML for years. Leveraging existing industry AI/ML efforts and data to begin to alleviate the AI/ML data gap is recommended. A large portion of government support efforts are run by DOD contractors, where they collect, analyze and report on our data. Utilizing the formal request for information (RFI) process would provide useful information on what data and capabilities exist, as well as which vendors are poised to facilitate information requests and respond to proposals.

7. Training and Documentation

A system with artificial intelligence as a decision aid will undoubtedly require some form of training beyond what the end users experience in the classroom and thorough documentation. Training is usually an expensive component of system deployment, as well as an on-going cost. Documentation is important for when the system inevitably is due for an upgrade or expansion of capability. Good documentation will allow new developers to understand the system and be able to implement updates quickly and readily.

Another major cost of any software system is ongoing development and expansion of capability. The upgrades can take many forms, including bug fixes, security updates or new features. It is often difficult or downright impossible to change contractors when the data rights are not owned by the DOD. It is important that the DOD acquire the data rights to the system. Owning the data rights should reduce the overall cost of the system and allow for tighter control of its development.

E. AREAS FOR FUTURE RESEARCH

As with any new technology, there is a plethora of opportunities for additional research. The team has identified several key areas including simulations, training, and data handling.

1. Human-Machine Teaming

Human-Machine teaming is a relatively new topic within engineering that is vital to the success of an AI-enabled decision aid. The interactions between the human and machine need to be seamless; the human should feel as if the machine is a welcome resource to their decision making toolbelt. The expectations of the machine, including any reasoning it used to deduce the list of recommendations, must be established before the design begins. Furthermore, the graphical, auditory and/or touch notifications the machine uses to inform/interact with the user must be designed so that the information is not overwhelming. Only the most important information is to be provided, in a clean/concise/complete method so as to not confuse the human. Future research into the specific interactions between humans and machines, and how the machine conveys its results to the human is recommended by the WRAID team.

2. Cognitive Engineering

While 35 years old, more research is needed to connect systems engineering with cognitive engineering (CE). CE is more than just human factors or human systems interfaces, or cognitive research. Systems like WRAID and other AI enabled systems are designed to help humans think, reason, and decide with more information, but if no thought is applied to how that information is presented, such information can overwhelm staff and decision makers. The human brain is limited in the number of bits of information that it can handle. Developing an interface that recognizes this is important to having a useful WRAID system with valuable input to the commander.

3. Formal Model-Based Systems Engineering

WRAID-like systems require sophisticated programming. AI enabled systems are a new category of systems. Since they are an emerging technology, they will require many updates in the beginning, as the kinks are ironed out. Changing software is expensive, time consuming, and not always successful. If SE used formal models, that were logically sound, then software might be produced directly from those formal models. Then all that is needed to change the software, is to change the model, and retransform into the new code. Such an approach might reduce the time required to effect changes and improvements. The Navy engineering community has already embraced MBSE, but so far not formal methods. Now, as the Navy seeks to implement a very complex WRAID approach, might be the right time to embrace formal MBSE, or at least research its potential.

F. SUMMARY

In summary, an AI-enabled WRAID system is feasible in the near term. With the current pace of technological advancement, if not developed by the U.S. or her allies, this capability (technology) will be realized by some peer competitor nation. To exploit battlespace advantages, it is imperative that the Navy lead the charge in driving toward an AI enabled future. There are several large operational and cultural challenges that must be met and quelled with a unified and unyielding directive. The biggest hurdles WRAID, or any other AI system face, are essentially infrastructure-based data and collaboration. If the infrastructure to feed AI systems was in place, systems like WRAID would probably already have been realized. An organizational top-down, directive mandating data standardization, storage, format, as well as compulsory collaboration and data sharing between all military branches is needed. Anything less would result in the continued disjointed effort, propagating the “we have always done it this way” mentality. What is required is to dedicate substantial resources, introduce operational changes, lead cultural changes, restructure systems engineering, and lastly address the glaring cyber-security and procurement changes; idealizing WRAID is no trivial task. However, it is vital to ensure battlespace superiority now and in the future.

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