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ARTIFICIAL INTELLIGENCE-ENABLED MULTI-MISSION RESOURCE ALLOCATION TACTICAL DECISION AID

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE REPORT

ARTIFICIAL INTELLIGENCE-ENABLED MULTI-MISSION RESOURCE ALLOCATION TACTICAL DECISION AID

by

Christopher J. Ghigliotti, Tara R. Sprinkle,
and Kelly W. Tesch

September 2022

Advisor: Bonnie W. Johnson
Co-Advisor: Scot A. Miller

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13. ABSTRACT (maximum 200 words)

The Department of Defense supports many military platforms that execute multiple missions simultaneously. Platforms such as watercraft, aircraft, and land convoys support multiple missions over domains such as air and missile defense, anti-submarine warfare, strike operations, fires in support of ground operations, intelligence sensing and reconnaissance. However, major challenges to the human decision-maker exist in allocating these multi-mission resources such as the growth in battle-tempo, scale, and complexity of available platforms. This capstone study seeks to apply systems engineering to analyze the multi-mission resource allocation (MMRA) problem set to further enable artificial intelligence (AI) and machine learning tools to aid human decision-makers for initial and dynamic re-planning. To approach this problem, the study characterizes inputs and outputs of a potential MMRA process, then analyzes the scalability and complexity across three unique use cases: directed energy convoy protection, aviation support, and a carrier strike group. The critical findings of these diverse use cases were then assessed for similarities and differences to further understand commonalities for a joint AI-enabled MMRA tool.

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Christopher J. Ghigliotti, Tara R. Sprinkle, and Kelly W. Tesch

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requirements for the degree of

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ABSTRACT

The Department of Defense supports many military platforms that execute multiple missions simultaneously. Platforms such as watercraft, aircraft, and land convoys support multiple missions over domains such as air and missile defense, anti-submarine warfare, strike operations, fires in support of ground operations, intelligence sensing and reconnaissance. However, major challenges to the human decision-maker exist in allocating these multi-mission resources such as the growth in battle-tempo, scale, and complexity of available platforms. This capstone study seeks to apply systems engineering to analyze the multi-mission resource allocation (MMRA) problem set to further enable artificial intelligence (AI) and machine learning tools to aid human decision-makers for initial and dynamic re-planning. To approach this problem, the study characterizes inputs and outputs of a potential MMRA process, then analyzes the scalability and complexity across three unique use cases: directed energy convoy protection, aviation support, and a carrier strike group. The critical findings of these diverse use cases were then assessed for similarities and differences to further understand commonalities for a joint AI-enabled MMRA tool.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAW	anti-air warfare
ABL	Airborne Laser
ACS	aircraft support
AI	artificial intelligence
AR	army regulation
ASCM	anti-ship cruise missile
ASE	aircraft survivability equipment
ASROC	anti-submarine rocket
ASUW	anti-surface warfare
ASW	anti-submarine warfare
BMD	ballistic missile defense
C&C	command and control
CIWS	Close-In Weapons System
COA	courses of action
C-RAM	counter rocket, artillery, and mortar
CSG	carrier strike group
C-UAS	counter unmanned aerial system
DE	directed energy
DOD	Department of Defense
DODAF	DOD architecture framework
ER	emergency response
ERE	Entropy Reduction Engine
ESSM	Evolved SeaSparrow Missile
EW	electronic warfare
FLRAA	Future Long Range Assault Aircraft
FM	field manual
FVL	Future Vertical Lift
FY	fiscal year

HEL	high energy laser
HMMWV	high mobility, multipurpose, wheeled vehicle
HPM	high-power microwave
MRAP	mine-resistant ambush protected
HSI	human systems integration
MTVR	medium tactical vehicle-replacement
INTL	intelligence
I/O	input/output
ISR	intelligence, surveillance, and reconnaissance
LEAD	Letterkenny Army Depot
LVC	live virtual constructive
MEDEVAC	medical evacuation
METT-TC	mission, enemy, terrain, troops available, time, and civilian considerations
ML	machine learning
MMRA	multi-mission resource allocation
MOE	measure of effectiveness
MOP	measure of performance
M-SHORAD	Maneuver-Short Range Air Defense
NAIIA	National Artificial Intelligence Initiative Act
NASA	National Aeronautics and Space Administration
NSWC	Naval Surface Warfare Center
OPNAV	Office of the Chief of Naval Operations
OV-1	operational viewpoint one
RAM	rocket, artillery, mortar
RCN	reconnaissance
RESUP	resupply
SE	systems engineering
SOCOM	special operations command
SOM	scheme of maneuver
SoS	Systems of Systems

STK	strike
SV	surveillance
UAH	Up-Armored HMMWV
UAS	unmanned aerial system
U.S.	United States
USN	United States Navy
WRAID	Wargaming Real-time AI Decision-Aid

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EXECUTIVE SUMMARY

Through this Naval Postgraduate School capstone (NPS) study, Team Artificial Intelligence (AI) Trio utilized a systems engineering (SE) approach to research how AI-assisted Multi-Mission Resource Allocation (MMRA) can benefit mission planners in all branches of service. This study, driven by the need to optimize the MMRA problem set within our Armed Forces, is critical for tactical leaders to effectively manage available resources. An opportunity exists to team human decision makers with an AI-enabled MMRA planning tool. This is facilitated by the rapid technical advancements in computing speed, data storage, and overall public acceptance in commercial applications.

The team approached the MMRA problem set from three mission sets: convoy protection, aviation support, and a Carrier Strike Group (CSG) operations. The convoy protection use case explored mobile ground-based air defense systems, utilizing directed energy (DE). The aviation use case explored the capability sets of the U.S. Army's Future Vertical Long-Range Assault Aircraft (FLRAA), a Future Vertical Lift (FVL) pre-Milestone B program. Lastly, the CSG use case explored MMRA from a highly complex System of Systems (SoS) perspective.

Although the use cases are diverse, the team explored similarities and contradictions among the perspectives. Each use case applied a general MMRA process architecture. However, the inputs and outputs were evaluated individually for each use case. Figure A depicts the overall MMRA process architecture.

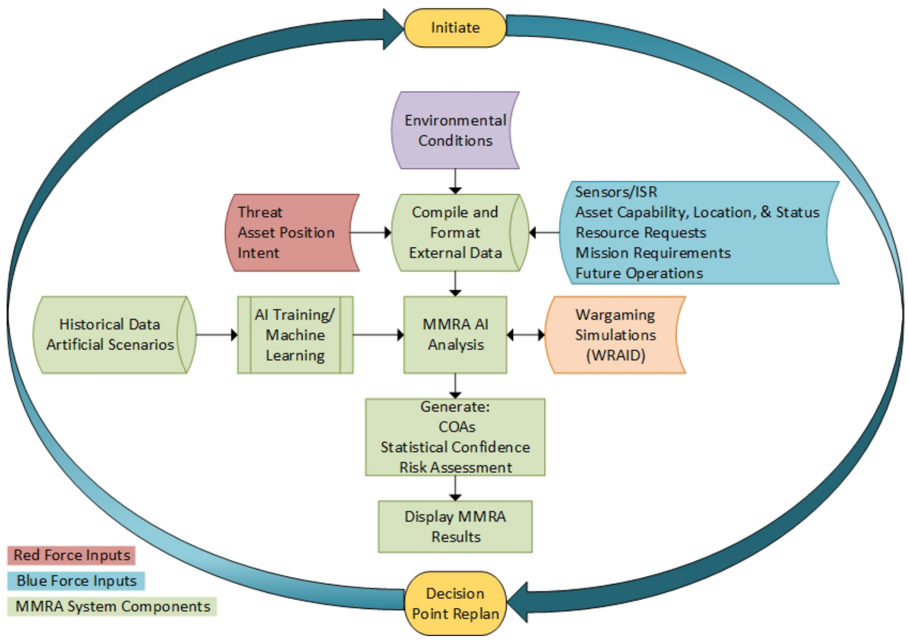

Figure A. MMRA Process Architecture "Recycle Chart"

As shown in Figure A, the MMRA is envisioned to be activated by a human-in-the-loop at determined decision points. At these events, the MMRA system is cycled once with real-time inputs. The outputs determined by the black box MMRA system are displayed to the human-in-the-loop for standard decision-making procedures. Although this study was limited to problem decomposition, an area for future research exists to develop a Human Systems Integration (HSI)-driven product realization. The MMRA enhances chain-of-command decisions by providing an objective evaluation of an increasingly complex and inter-dependent resource allocation problem. Figure B depicts the action diagram for the MMRA AI system process.

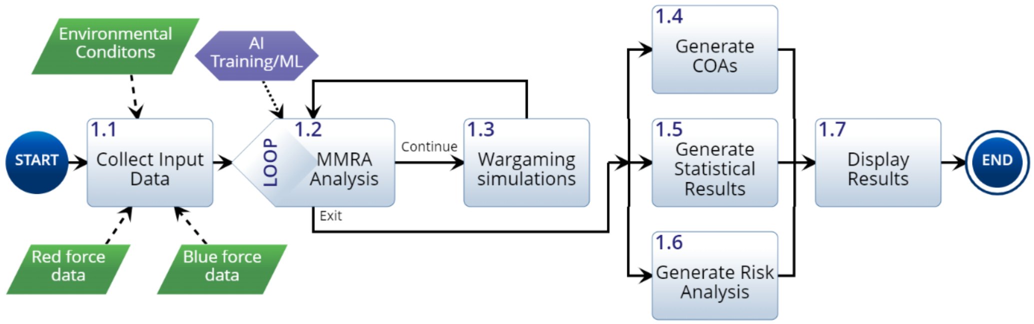

Figure B. MMRA Process Architecture Action Diagram

MMRA decision-making is already beyond the complexity level for traditional decision-making processes. This complexity applies at all levels of mission planning. The tactical level is conducted at the individual soldier's immediate chain-of-command or unit level. The operational and strategic perspectives are conducted at the echelon or headquarters level. All require accurate and efficient allocation of available resources.

The graphic in Figure C, "Tactical Evaluation Process: MMRA Decision Complexity," depicts how MMRA is conducted over time at decision points in an operational scenario. Initial planning is conducted at t_0 which correlates to the "Initial" yellow activity block in the "MMRA Process Architecture." Sometime later the t_1, t_2, t_3, …, t_n decision points correlate to the "Decision Point Replan" yellow activity in the "MMRA Process Flow." Both "Initial" and "Decision Point Replan" yellow activity blocks initiate a complete MMRA Process Flow, which encompasses all the activities depicted inside the "Initial" and "Decision Point Replan" continuum.

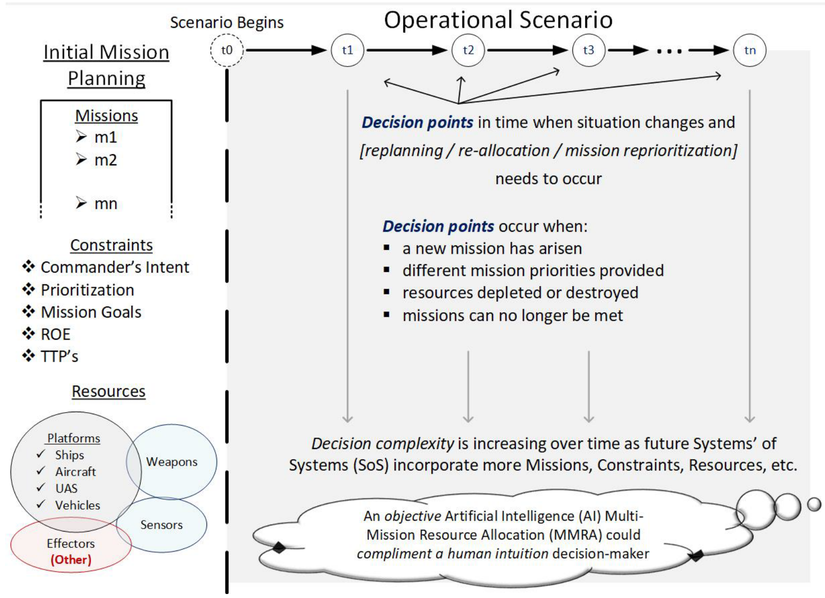

Figure C. Tactical Evaluation Process – MMRA Decision Complexity

Decision points are commonly defined across the three MMRA use cases. However, unique storylines specific to the envisioned scenario are applied for context. Although all cases cannot be listed here, an example of a CSG unique decision point was an emergency response either within the CSG, external to the CSG, or a natural disaster aid response. Commonly, all decision points occurred when a new mission arose, different mission priorities were provided, resources were depleted, resources were destroyed, or the mission could no longer be met.

To better understand the scope of the MMRA problem set, the team conducted scalability and complexity analyses on all three use cases. The scalability analysis captured the scope of the static MMRA problem set in comparison to that use case's historical context. Thus, the scalability analysis gave a context of the initial MMRA planning problem set from legacy systems to present use case scenarios. The DE Convoy Protection and CSG use cases both saw an unquantifiable increase in scalability. For DE Convoy Protection the red force capability increased due to technological advancements with precision attacks. Further, the CSG blue force capability increased, in some places three-fold, with expanded countermeasure capability, missile-type availability, and quantities between the different classes of destroyers. Complementary, the aviation use case yielded a 15% scalability increase from the legacy utility-class helicopter to the FVL FLRAA.

The complexity analysis captured the scope of the dynamic MMRA problem set in comparison to the respective use case's historical context. These complexity analyses provided further MMRA context, as tactical decision-making occurs at multiple decision points when MMRA is replanned in an engagement. All three use case complexity analyses constructed storylines demonstrating intangible, increasingly challenging MMRA considerations. The future critical need for an AI-assisted MMRA decision-making becomes clear as the scalability and complexity of MMRA increases over time.

Continued decomposition of the AI-assisted MMRA problem set may be of interest to the U.S. Armed Forces. In all use cases, the tactical decision-making complexity was shown to increase over time in both initial and replanning operational scenarios. It is strongly recommended that the AI-enabled MMRA problem set be further studied. Areas identified for future research are multiples of tooling, hardware/software deployment strategy, tactical versus operational versus strategic level resourcing, continuous versus discrete replanning tempo, AI machine learning considerations such as quantity/quality data, AI acceptance from humans-in-the-loop, AI output dashboard display, and AI ethics.

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Thank you, Dr. Bonnie Johnson and CAPT (ret) Scot Miller, for your guidance, wisdom, and going above and beyond to help our capstone come together. Thanks to our friends and coworkers, who supported us, offered advice, and stepped up to take on tasks so we could focus on our studies. Special thanks to our spouses and families, who sacrificed and supported us throughout this program. We could not have done this without you.

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I. INTRODUCTION

A. BACKGROUND

Artificial intelligence (AI) technology has improved tremendously, even in the past few years. People benefit from the improvement in AI systems in our everyday lives. Examples include music streaming applications suggesting new artists based on historical play, and the smart-watch capability to detect an impending cardiac event. These highlight how AI is permeating everyday life. An important component to the continued advancement of AI is machine learning (ML). Through ML, computers are already consistently outperforming humans in gaming (Goodman, Lucas, and Risi 2020). With every breakthrough in this technology the benefits of utilizing AI to help in human decision-making are expanding.

Similarly, military technology has also evolved and become more complex. As the systems and capabilities expand, the decision-making process for resource allocation also becomes more complex. At the same time, budgets for resources can only grow at a certain pace. This limits the resources available for different mission requirements. Resource over-allocation in multi-mission scenarios can result in reduced capability for each mission commander to execute effectively. With such complex missions, military decision makers must grapple with the challenge of resource optimization to fulfill the different missions. A military unit deploys with a fixed number of resources. As technology expands and the resources are equipped to handle increasing mission sets, the cognitive burden on decision makers to allocate resources easily becomes overwhelming. No tool currently exists to provide consistent, mission-optimized resource allocation. Multi-mission resource allocation (MMRA) using AI could significantly improve outcomes for tactical and strategic planning.

A capability gap is narrowing between the United States (U.S.) and near-peer adversaries. Multiple near-peers publish statements about their capabilities, especially pertaining to hot-topics such as AI. However, all statements in the public domain about emerging technologies should be taken with a healthy dose of skepticism. Political motivations are embedded in all public statements. Despite the embellishment, a significant rise in the rate of AI investments is indicative of real power races among competitors. To compete, the U.S. launched the National Artificial Intelligence Initiative Act (NAIIA) of 2020. In a statement by the White House in January 2021, "the U.S. remains the world leader in AI. The White House's new National AI Initiative Office will be integral to the Federal Government's efforts to maintain this leadership position for many years to come" (Office of Science and Technology Policy, 2021). The continued support of the NAIIA in subsequent national budgets will maintain U.S. capability to compete with her adversaries through supporting stateside industry, academia, and policymakers.

There is an opportunity for the use of AI to aid in resource optimization in multi-mission scenarios. Today, military leaders have a tremendous burden to effectively execute missions with finite resources in an increasingly complex war space. The limits of human processing in this arena have long since been exceeded. However, there is an opportunity for an AI-assisted MMRA tool to aid mission planners. Through AI and ML, courses of action (COA) can easily be computed and displayed for use. Decision makers can employ the technology to improve situational awareness in real-time and adjust resources swiftly in response to the changing environment. An AI-assisted MMRA tool can even alert commanding officers to a change in the situation which may require re-allocation of resources. Algorithms can expeditiously run through different scenarios, balance the limited resources in competing mission areas, and present likely outcomes for the different COA presented. This capstone explores the complex military problem set of MMRA. The research also focuses on how AI and ML can help decision makers. Military outcomes can be improved through better situational awareness, mission and resource prioritization, decreased re-planning reaction times, and data-driven COA in tactical real time situations. AI and ML are likely the key to the solution set for MMRA.

B. PROBLEM STATEMENT

Research sponsor Bill Treadway (OPNAV N2/N6) noted that

> Many military platforms are inherently multi-mission—they execute a variety of missions simultaneously. Ships, submarines, and aircraft support multiple missions across domains, such as air and missile defense, anti-

> submarine warfare, strike operations, fires in support of ground operations, and intelligence, surveillance, and reconnaissance. Scheduling and positioning of these multi-mission platforms are problematic since one warfare area commander desires one position and schedule, while another may have a completely different approach. Commanders struggle to decide and adjudicate these conflicts, because there is plenty of uncertainty about the enemy and the environment. (Johnson 2022)

Additionally, the complexity of warfare continues expanding, yet naval forces only have a finite number of warfare resources to execute these multiple missions. Current multi-mission planning tools available to mission commanders are inadequate. Mission planners need better tools to maximize resource efficiency, and quickly re-allocate when necessary. This capstone investigates ways to improve MMRA using AI.

C. PROJECT OBJECTIVES

The primary objective of this capstone was to explore how AI can aid mission planners and warfighters in effective MMRA for initial planning and dynamic replanning.

Supporting objectives included:

1. Characterizing complex military situations involving situations of multiple concurrent missions and limited resources
2. Characterizing these complex situations from a system context perspective: identifying inputs, controls, outputs, and mechanisms required of the AI-enabled MMRA capability which would support mission planners by optimizing their limited warfare resources across mission areas.
3. Developing a high-level conceptual design of an AI-enabled MMRA capability.
4. Evaluating the similarities and differences an AI-enabled MMRA capability requires in different tactical scenarios.

D. TEAM ORGANIZATION

The roles of the three members of Team AI Trio are as follows:

Team Lead: Tara RuthAnn Sprinkle is responsible for the weekly minutes with the advisors, organizing the meetings, and participating in and contributing to all aspects of the capstone project.

Mrs. Tara RuthAnn Sprinkle is a Software Engineer, DB-0854-03, with the Software, Simulation, Systems Engineering and Integration Directorate Technical Management Division at Redstone Arsenal, Alabama. As an effort to modernize, the Army's Future Vertical Lift (FVL) mission is to increase reach, protection, and lethality through five aviation lines of effort: future attack reconnaissance aircraft, Future Long-Range Assault Aircraft (FLRAA), future unmanned aerial systems, modular open system architecture, and air launched effects. Mrs. Sprinkle is currently matrixed to support the Army's FVL FLRAA program office and has her organization's support to capture a FLRAA MMRA FVL use case.

Lead Editor: Kelly Tesch is responsible for final editing of the documentation, entry into Python, maintaining the official team schedule, and participating in and contributing to all aspects of the capstone project.

Ms. Tesch has worked since 2001 at the Naval Surface Warfare Center, Corona Division (NSWC Corona). From 2001–2018, Kelly worked as a missile flight analyst for the Performance Assessment Department supporting the NATO Seasparrow Project Office. In 2018, Kelly transferred to the Range Systems Engineering Department at NSWC Corona where she is now the branch manager for the project management branch. The project management branch supports the tactical training ranges for multiple branches of service and coalition partners.

Lead Analyst: Christopher Ghigliotti is responsible for leading the analysis portion of the capstone, final check of all analysis submitted by other team members and participating in and contributing to all aspects of the capstone project.

Mr. Ghigliotti works at Letterkenny Army Depot (LEAD) located in Chambersburg, PA. In the Office of Strategic Management Directorate, Mr. Ghigliotti is the Lead Electronics Engineer supporting the development of sustainment capabilities for directed energy (DE) and radar systems at LEAD. This includes working with Department of Defense (DOD) Program Management offices and Original Equipment Manufacturers to identify requirements for and the purchase of facilities and equipment for these efforts. In support of the DE community, Mr. Ghigliotti is working with the Directed Energy Professional Society to develop and carry out a DE science technology engineering math outreach program. Mr. Ghigliotti is also a LEAD subject matter expert providing support in the areas of the Patriot missile defense system, advanced manufacturing, and test program set development.

E. PROJECT APPROACH

The team approached the MMRA problem set from three mission sets: aviation, convoy protection, and a CSG. Specifically, the convoy protection use case explored ground-based defense system, utilizing DE effects. The aviation use case explored the capability sets of the U.S. Army's FLRAA, a FVL pre-Milestone B program. Lastly, the CSG use case explored MMRA from a highly complex System of Systems (SoS) perspective.

Although the use cases are diverse, the team explored similarities and contradictions among the perspectives. Each use case applied a general MMRA process architecture. However, the inputs and outputs were evaluated individually for each use case.

To better understand the scope of the MMRA problem set the team conducted scalability and complexity analyses on all three use cases. The scalability analysis captured the scope of the static MMRA problem set in comparison to that use case's historical context. Thus, the scalability analysis gave a context of the initial MMRA planning problem set from legacy systems to present use cases. The complexity analysis captured the scope of the dynamic MMRA problem set in comparison to the respective use case's historical context. These complexity analyses provided further MMRA context as tactical decision-making occurs at multiple decision points when MMRA is replanned in an engagement. The future critical need for AI assisting the human MMRA decision becomes clear as the scalability and complexity of MMRA increases over time.

F. REPORT ORGANIZATION

This chapter provides a background, defines the problems, identifies the research objectives, introduces the team, describes the project approach, and provides an overview of the proposed solution concept. Chapter II, the literature review, dives deeper into AI, current techniques for making mission allocation trades, identifies AI technology techniques and reviews previous research incorporated into this report from the systems engineering (SE) capstone Team "WRAID" (Wargaming Real-time AI Decision-Making). Further, Chapter III deep-dives the proposed AI-enabled MMRA system concept such as SE problem decomposition architecture. Chapter IV walks the reader through the three operational vignettes. In this chapter, the SE rigorous analysis is executed to demonstrate the research objectives and compares MMRA across the three vignettes. Later, the last two chapters are dedicated to understanding the results of the Capstone report. Chapter V included an analysis of applications through comparing similarities and differences, and states additional considerations were not considered in the study but are related. Lastly, Chapter VI provides the summary, recommendations, and areas for future research.

II. LITERATURE REVIEW

The initial phase of this capstone report was a literature review of pertinent MMRA topics. Team AI Trio began the problem decomposition with literature review research into a broad range of military mission planning procedures, current AI technological capability, theorized AI-assisted MMRA techniques, and postulated AI-enabled Wargaming.

A strong foundation of the current academic body of knowledge was key to transitioning into later phases of the capstone report. Valuable information gleaned in the literature review was flowed into the Chapter III analysis of MMRA use cases. The three use cases conducted were diverse in complexity by design. However, all were able to be analyzed with a common understanding of AI-enabled MMRA capabilities. The outcome of the conducted literature review was a more robust and reliable systems engineering (SE) study of project decomposition.

A. MILITARY MISSION AND PLANNING

At present, there is no single tool utilized for mission planners to allocate resources. Instead, documents such as the DOD Mission Assurance Strategy help guide planners into resource allocation through prioritization of missions. The directive focuses on four pillars of execution to ensure the DOD mission is met (Deputy Secretary of Defense 2012). However, the strategy focuses on the "what," not the "how" of resource allocation. This leaves mission planners on their own to determine the best allocation of resources. With no decision aids readily available, resource allocation is left to best practice and corporate knowledge. Clearly, there is room for optimization of resource allocation using AI.

A key overview of the military mission planning process is taught at the Joint Targeting School. The student guide is a cornerstone training doctrine that spans the entire U.S. Armed Forces. The latest revision was published in 2017 and covers critical concepts for military decision makers such as the formal planning process and differentiation between deliberate targeting (initial planning, t_0) and dynamic targeting (replanning, t_n).

The military planning process has formal doctrine that guides decision makers to the best, most consistent critical analysis. This formal military doctrine describes "what" should be expected through each of the seven phases as shown in Figure 1. Like the gap in resource allocation, mission planning relies heavily on precise commander guidance and effective continuous communication.

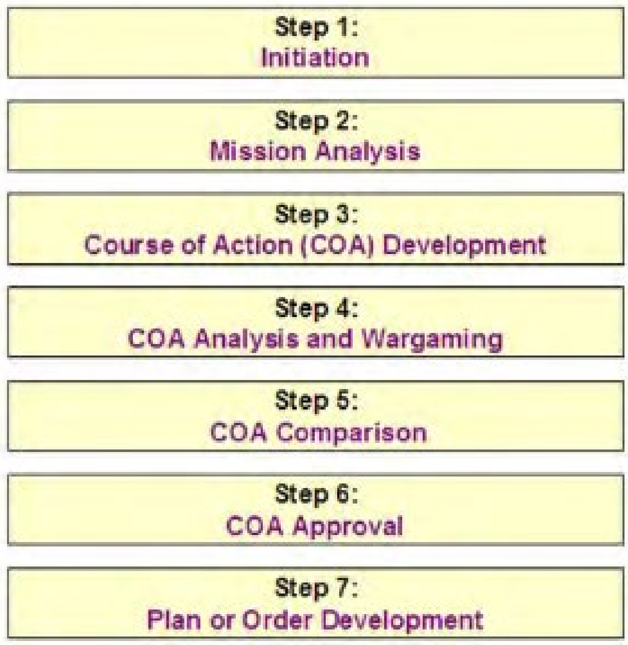

Figure 1. Military Planning Process Steps. Source: Joint Targeting School (2017, 7).

> Joint fire support planning is an integral part of the overall planning process. Joint fire support planners and/or coordinators actively participate with other members of the staff to develop estimates, give the commander recommendations, develop the joint fire support portion of the CONOPS, and supervise the execution of the commander's decision. The effectiveness of their planning and coordination is predicated on the commander providing clear and precise guidance. Joint fire support planning and coordination ensures all available joint fire support is synchronized in accordance with the JFC's plan. The key to effective integration of joint fire support is the thorough and continuous inclusion of all component fire support elements (FSEs) in the joint planning process, aggressive coordination efforts, and a vigorous execution of the plan. Commanders should not rely solely on their joint fire support agencies to plan and coordinate joint fire support. A continuous dialogue between the commander, subordinate commanders, and joint fire support planners must occur. (Joint Targeting School 2017, 73)

Shown in Figure 2, the Joint Targeting School clearly delineates between deliberate targeting (initial planning, t_0) and dynamic targeting (replanning, t_n). Deliberate targeting occurs when scheduled and on-call targets are recognized. Reciprocally, dynamic targeting occurs when targets of opportunity arise in the replanning cycle. The allocation of mission resources is directly tied to these initial and replanning events.

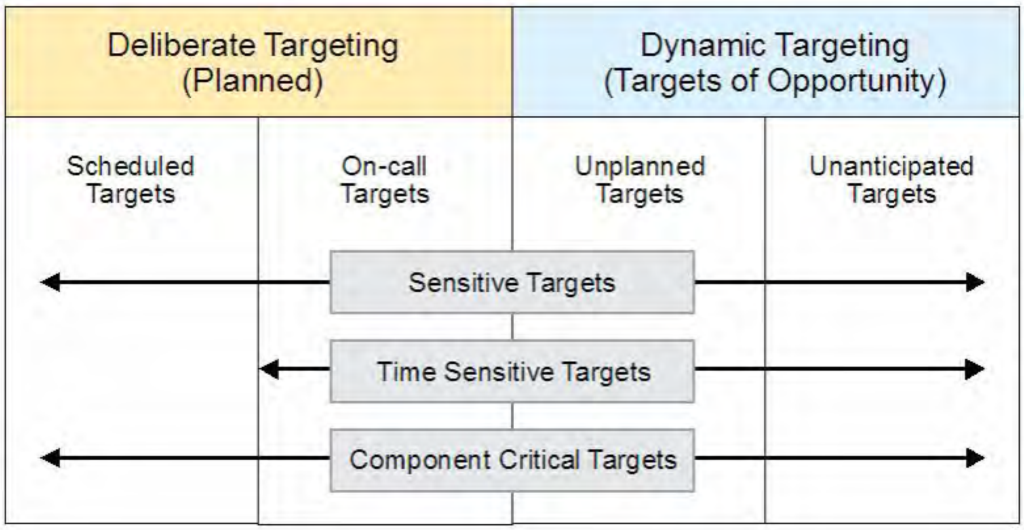

Figure 2. Categories of Targeting and Targets. Source: Joint Targeting School (2017, 36).

The understanding of a dynamic targeting event can be broad and challenging to see in the fray and friction of conflict. However, the Joint Targeting School provides rhetoric for this categorization.

> Dynamic targeting is normally employed in current operations planning because the nature and timeframe (usually the current 24-hour period) typically requires more immediate responsiveness than is achieved in deliberate targeting. Current operational planning addresses the immediate or very near-term planning issues associated with ongoing operations which usually occur in the joint operations center (JOC) under the operations directorate of a joint staff (J-3). Dynamic targeting prosecutes changes to planned targets or objectives and targets of opportunity. (Joint Targeting School 2017, 36)

B. ARTIFICIAL INTELLIGENCE

The MMRA concept of this capstone relies heavily on AI. AI is an emerging technology that is currently the focus of much research. The human capability is quickly exceeded with a complex problem such as MMRA. In the article "Artificial Intelligence—an Enabler of Naval Tactical Decision Superiority" Dr. Bonnie Johnson observes that "a future goal in human-to-AI teaming is to enable AI to take the computational load off people" (Johnson, Artificial Intelligence—an Enabler of Naval Tactical Decision Superiority 2019). Researchers have already demonstrated that AI systems can outperform humans in certain engagement spaces. Goodman, Lucas, and Risi demonstrate in their dissertation "AI and Wargaming" that AI can now consistently match or surpass humans in games such as chess (Goodman, Lucas, and Risi 2020). The DOD has been investing heavily in AI research. In a December 8, 2021 memo, the Deputy Secretary of Defense created a Chief Digital and AI Officer "responsible for strengthening and integrating data, artificial intelligence, and digital solutions in the Department" (Deputy SECDEF 2021). Team AI Trio postulates that before long the concept of AI to assist in MMRA for the DOD will be a reality.

The Army Research Laboratory wrote an article in which they described how the U.S. Army conducted game-theory research where AI is used to deploy resources more efficiently. The article also described a program developed by Carnegie Mellon University called Pluribus (United States Army CCDC Army Research Laboratory Public Affairs 2019). Pluribus "defeated leading professionals in six-player no-limit Texas hold'em poker" (United States Army CCDC Army Research Laboratory Public Affairs 2019).

> A limiting factor in game theory has always been scalability (i.e., ability to deal with exponentially increasing state space). Poker is an accessible example to show how these mathematical models can be used to devise strategies for situations where a person doesn't have complete information—they don't know what the adversaries will do, and what their capabilities are. —Dr. Purush Iyer (United States Army CCDC Army Research Laboratory Public Affairs 2019)

In the article, Noam Brown was quoted saying, "The ability to beat five other players in such a complicated game opens up new opportunities to use AI to solve a wide variety of real-world problems" (United States Army CCDC Army Research Laboratory Public Affairs 2019).

> The software also seeks to be unpredictable. For instance, betting would make sense if the AI held the best possible hand, but if the AI bets only when it has the best hand, opponents will quickly catch on. So, Pluribus calculates how it would act with every possible hand it could hold and then computes a strategy that is balanced across all of those possibilities. (United States Army CCDC Army Research Laboratory Public Affairs 2019)

AI is different from automation. "Automation substitutes human labor in tasks both physical and cognitive—especially those that are predictable and routine" (Gaynor 2020). AI on the other hand is "less about tasks and more about intelligence" (Gaynor 2020). Rather than being used for "routine" tasks, AI is looked to for planning, problem-solving, and perception (Gaynor 2020). To gain this intelligence, AI must learn through what is called ML. ML leverages the data sets on which many AI algorithms make its decisions. There are several different methods of ML such as neural networks, clustering, regression, and classifications. Even within just neural networks, there are different designs that are better suited to different types of information (IBM Cloud Education 2020). Two examples are word processing and image processing.

Two techniques of ML are supervised and unsupervised learning. As implied, through supervision machines learn information that has been labeled. With unsupervised learning, the machines must identify information without help (IBM Cloud Education 2020). With the incredible amount of information involved, new technology and technology standards are being developed such as the Tesla Dojo Technology, which allows for more information bandwidth by utilizing a configurable format in which the standard precision is not required for accuracy (Tesla n.d.). As AI technology increases in capability and computing resources required to run AI calculations improve, the use of AI to aid in MMRA will likely become increasingly feasible.

C. AI ASSISTED MMRA TECHNIQUES

Allocating resources has been a military problem since the establishment of the first organized unit. Even when the problem is distilled down to a single resource, MMRA can still prove problematic if that resource is in high demand. For example, the research scientists at the National Aeronautics and Space Administration (NASA) found that "telescopes have always been a scare resource, and astronomers have had to make do with limited access" (Swanson, Drummond, and Bresina 1992). Given this problem, the authors sought to apply the results of a previous project published by Drummond, Bresina, and Samadar Kedar called the Entropy Reduction Engine (ERE). The ERE sought to solve the linked issue of resource constraints and time constraints for a given stated goal (Drummond, Bresina, and Kedar 1991). Interest in AI assisted MMRA has only grown since the time the NASA Ames researchers were seeking a solution to their telescope scheduling issue. In addition, as technology becomes more complex many systems can support multiple different missions and use cases. This drives a need for coordination within the SoS domain to allocate individual resources. Like NASA, the DOD often finds the resources allocated must be shared between different missions and prioritized. Current research is focusing on leveraging AI to help inform decision makers to maintain the tactical advantage in an increasingly complex battlespace (Johnson 2019).

Rooted in DOD doctrine, an AI-assisted MMRA tool could follow the intent established by the Joint Targeting School. However, for an AI system various areas of the DOD decision-making framework are more objective and appropriate for computer-aided delegation. Continuously processing through the targeting cycle via the dictated mission analysis inputs and outputs is one way an AI-assisted MMRA tool could excel in a process currently limited by human processing.

The targeting cycle is applied to all military mission re-planning events via the six-phase cycle depicted in Figure 3. Although the re-planning cycle is fluid, an initial commander's intent and objectives is needed. Then, subsequent target development, prioritization and capabilities are assessed. At this point, the human-in-the-loop decides and directs force assignments such as strategic and operational direction. Once initiated, an AI-assisted MMRA tool can cycle through an internal operating procedure to rapidly conduct MMRA for phase five and six. This would relieve the burden off the human and allow rapid processing through these phases. Lastly, the potential exists to achieve the end state; until the commander's initial intent or objectives change.

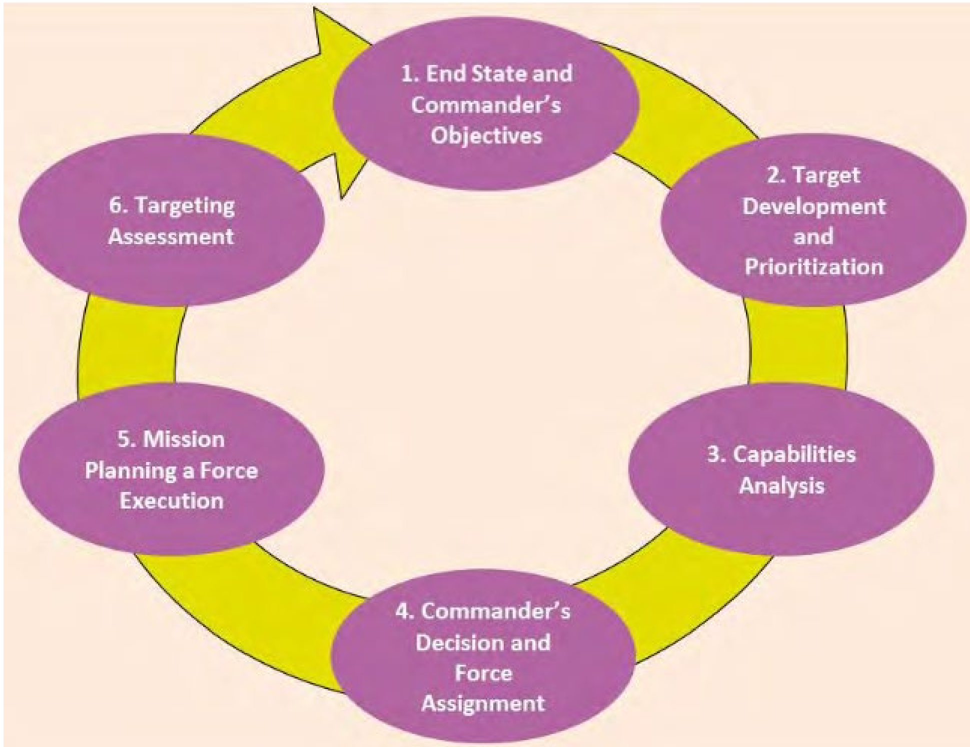

Figure 3. Military Mission Targeting Cycle. Source: Joint Targeting School (2017, 95).

A critical need exists to process through the targeting cycle faster and with greater fidelity. As the tempo of engagements speed up, the need for faster decision-making occurs. An AI-assisted MMRA tool may be tasked to ingest inputs in the targeting cycle and provide key outputs, in accordance with established Joint Targeting School doctrine. The mission analysis key inputs and outputs according to the Joint Targeting School are shown in Figure 4.

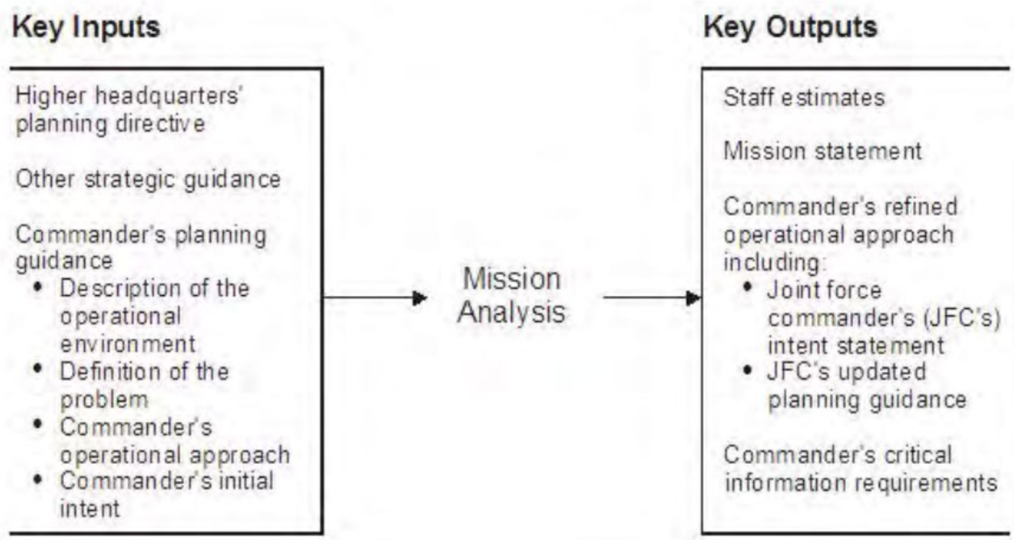

Figure 4. Military Mission Analysis – Inputs and Outputs. Source: Joint Targeting School (2017, 96).

D. REAL-TIME WARGAMING DECISION AIDS

Wargaming using AI has been one such area researchers have sought to solve the MMRA problem for the DOD. A former SE capstone team explored a WRAID system capability to support the future tactical warfighter (Badalyan et al. 2022). The WRAID capstone concept covers a single mission scenario where the outcome is optimized using AI and COA are presented to the commanding officer for consideration (Badalyan et al. 2022). Key outputs of the WRAID capstone were the requirements, a conceptual design, and a concept of operations for the WRAID system.

The WRAID is imagined at the center of the system. Inputs for a given scenario include asset locations for both blue and red forces, capabilities of the respective assets, environmental conditions, information from available sensors, and commander's intent. For this given snapshot in time, the WRAID computes COA for different scenarios and given the COA selected presents recommendations for orders. The WRAID is limited to wargaming, whereas the envisioned AI-assisted MMRA tool would expand upon the WRAID concept beyond combat scenarios to multiple missions. Figure 5 depicts an overview of the WRAID concept.

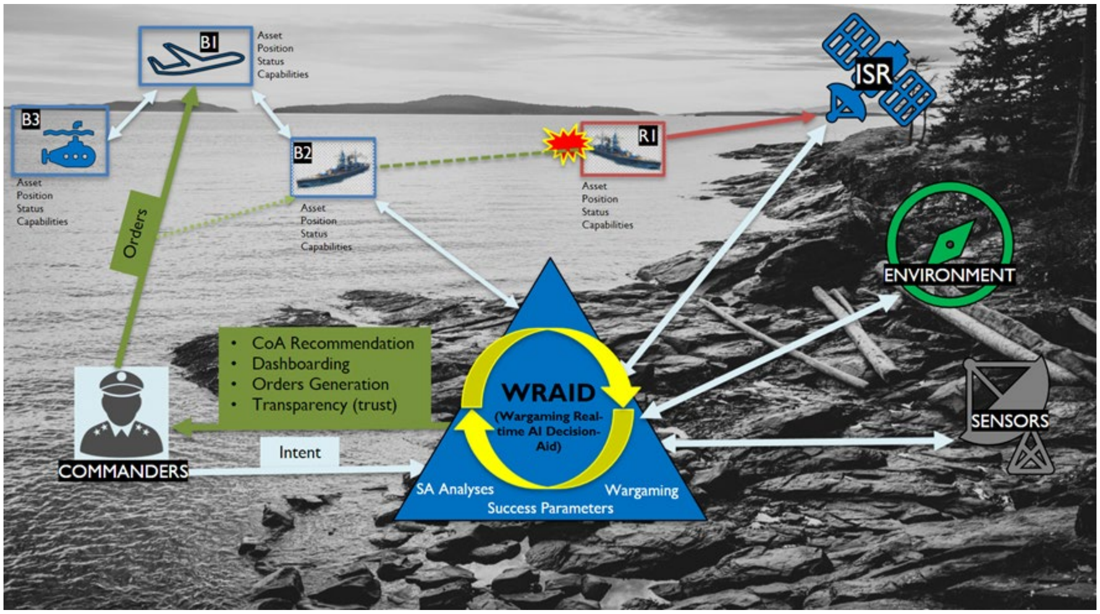

Figure 5. Team WRAID OV-1. Source: Badalyan et al. (2022).

The WRAID team also explored current wargaming capability using AI and ML techniques. Figure 6 depicts the overall concept of COA for a single mission to win the war. The WRAID system decomposes the objective with the available inputs for the scenario. Through AI and using the benefits of ML, the WRAID computes all available COA that result in the same desired mission end state. These COA are presented to the mission-planners and can aid commanding officers at critical decision points in the scenario. Figure 7 depicts the process flow inside the WRAID system.

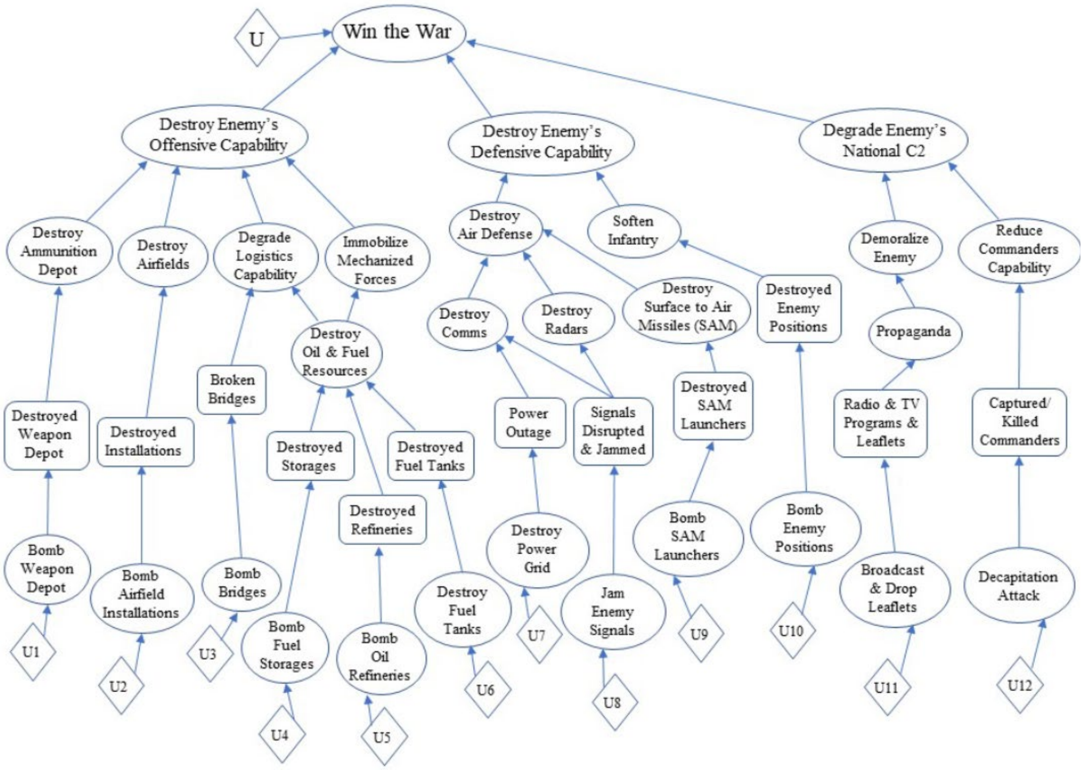

Figure 6. Military Courses of Action Diagram. Source: Johnson (2021).

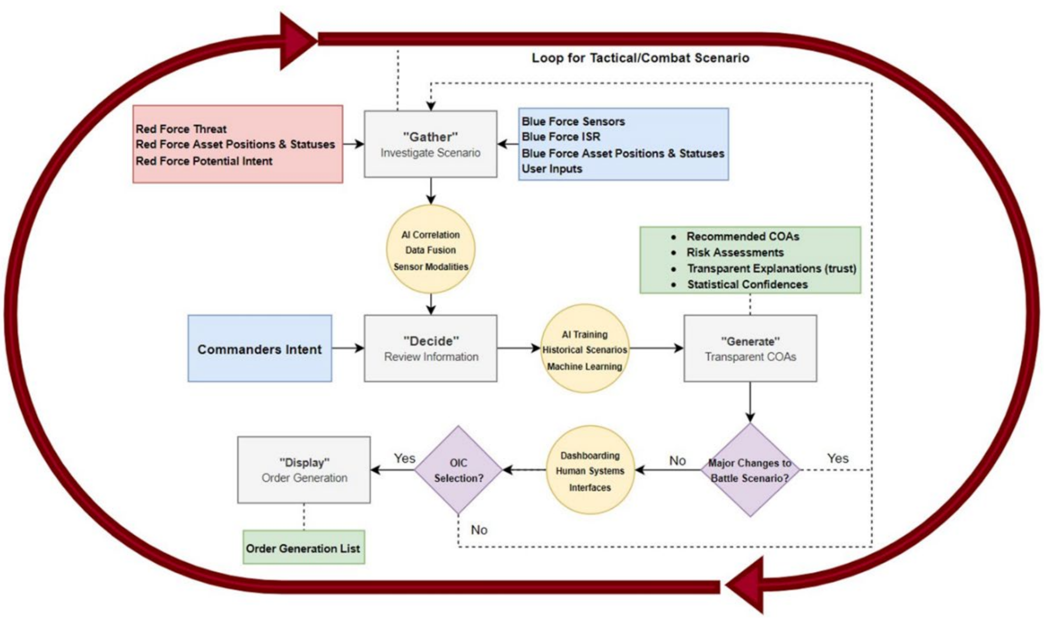

Figure 7. WRAID Planning and Decision-Making Process Workflow. Source: Badalyan et al. (2022, 58).

Team AI Trio incorporates and builds on the WRAID system as a black box without decomposing the WRAID system or exploring potential algorithms. The WRAID capstone report presented current techniques and research ongoing to support such a system. The WRAID team noted that “the Navy Command and Control Program Office PMW-150 is working on ingesting the various data streams required for the WRAID algorithm” (Badalyan et al. 2022, 60). Many of the same AI and ML concepts explored in the WRAID capstone are directly applicable to an AI-assisted MMRA tool. The WRAID system is incorporated into the MMRA AI process as a constituent system of the MMRA AI SoS.

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III. AI-ENABLED MULTI-MISSION RESOURCE ALLOCATION SYSTEM CONCEPT

To begin the process of developing a concept for the AI-enabled MMRA system, we considered the stakeholders and their key concerns. For the stakeholders, we identified Congress, the DOD, the major commands, the MMRA system users, and MMRA system developers as the primary stakeholders of the MMRA system. We listed the key concerns for these stakeholders in Table 1.

Table 1. Stakeholders and Key Concerns

Stakeholder	Key Concerns
Congress	Budgetary impact beyond the system Cost-effectiveness
Department of Defense	Maintaining technological edge over adversaries Interoperability across the services
Major Commands	System reliability Optimized allocation of resources Trust in MMRA AI outputs
MMRA AI Users	Reduce resource allocation decision time Optimized allocation of resources Reliable input data Trust in MMRA AI outputs System reliability Availability of MMRA AI system Ease of use in current mission sets
MMRA System Developers	Low manufacturing costs Achievable technology readiness levels System reliability System capable of processing large amounts of data

Next, we considered the inputs and outputs for this AI-enabled MMRA system. These were grouped into four groups: controllable inputs (inputs the system users/developers can control), uncontrollable inputs (inputs the system users/developers cannot control), intended outputs (desired end states), and unintended outputs (undesired end states). These inputs and outputs are depicted in an input/output (I/O) model shown in Figure 8.

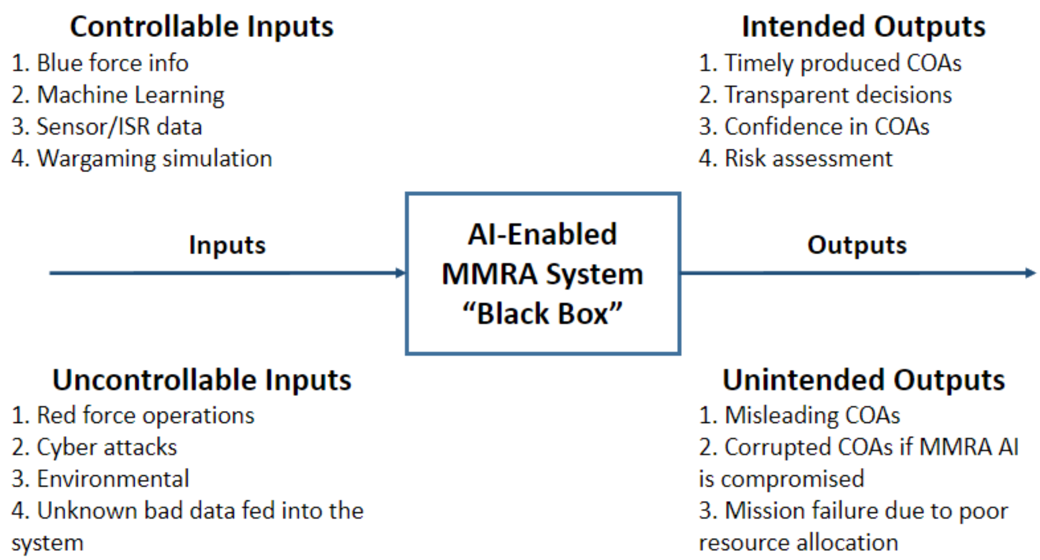

Figure 8. AI-Enabled MMRA System I/O Model

Considering the stakeholders need, a concept for an AI-enabled MMRA system was developed. The MMRA system was envisioned with a human-in-the-loop at discrete decision points. At these decision point events, the MMRA system would be cycled once with the inputs available at that given point in time. These inputs would include the latest information on red and blue forces which are also fed into wargaming simulations such as those performed by the WRAID system. This data would be combined and formatted for processing by the MMRA system. ML utilizing historical data and artificial scenarios would also feed into the MMRA system. The MMRA system then processes the data using algorithms designed to optimize the resource allocation and generates proposed COAs, statistical confidence, and risk assessments. These outputs are displayed to the human-in-the-loop for standard decision-making procedures. These outputs and the results of the chosen COAs would then be fed back into the system for inclusion in the historical data for ML purposes. Figure 9 depicts this process architecture for the MMRA system.

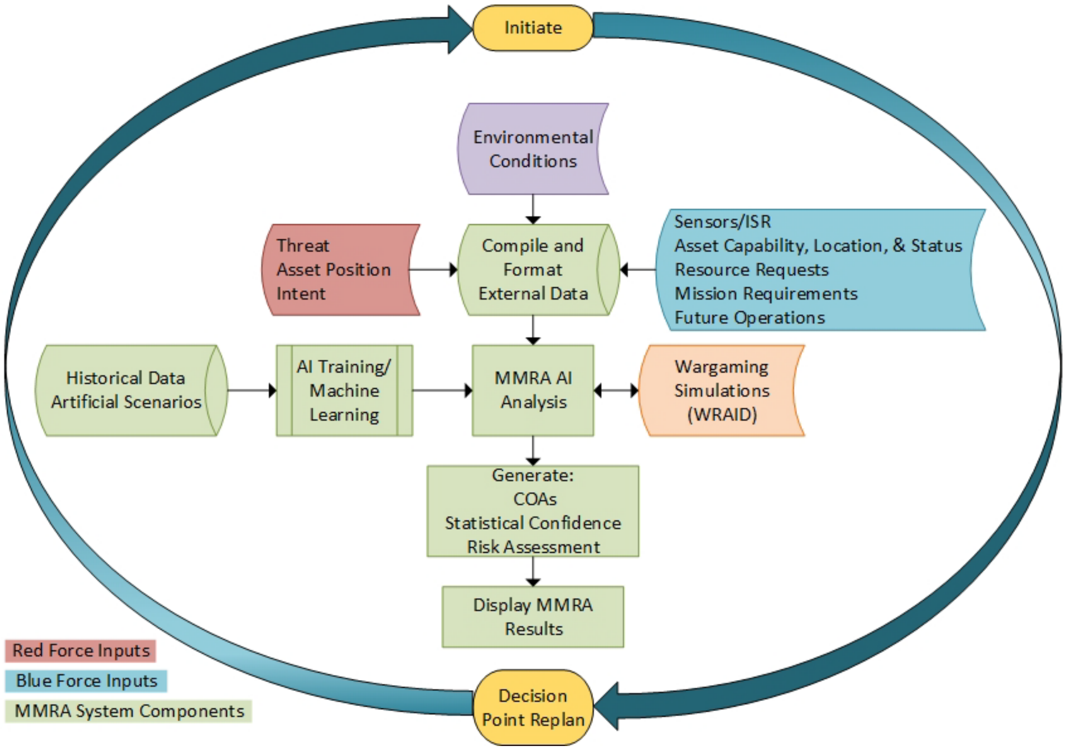

Figure 9. MMRA Process Architecture "Recycle Chart"

The MMRA enhances chain-of-command decisions by providing an objective evaluation in an ever increasingly complex and inter-dependent resource allocation problem. Figure 10 depicts the action diagram for the MMRA system process.

The first action takes all the available data from external data including intelligence on red forces, information on blue forces, commander's intent, and environmental conditions. The system compiles them into a format the MMRA system can use. The MMRA system takes that information and analyzes the various possible resource allocations, considering wargaming simulations based on the input data. The system outputs the resource allocation COAs with supporting statistical results and risk analysis. The goal of the statistical results and risk analysis is to bolster confidence in the AI outputs and aid decision makers in determining if the COAs will be effective. Lastly, these outputs are displayed to the system user considering human factors engineering. This ensures the information is presented in a way to minimize cognitive fatigue and maximize ease of decision-making. The process is captured in an action diagram shown in Figure 10.

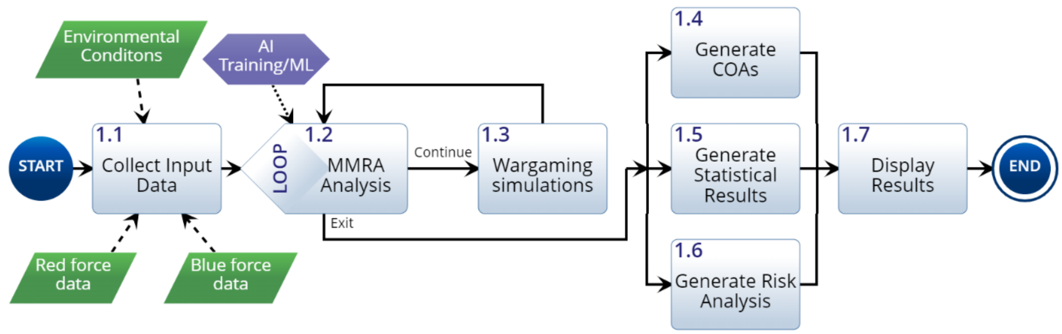

Figure 10. MMRA Process Architecture Action Diagram

MMRA decision making is becoming unreasonably complex even at the tactical level in the soldier's immediate chain-of-command. Contrarily, the operational and strategic perspectives are conducted at the headquarters. An AI-assisted MMRA system could help at all levels of decision-making.

A formal framework of the military guidance hierarchy is provided by the Joint Targeting School and depicted in Figure 11. The DOD-wide doctrine delineates four levels of guidance: national strategic, theater strategic, operational, and tactical. The tactical level is the most rudimentary level that decision makers provide mission guidance. Decision makers are trained to assess assigned objectives to measures of effectiveness (MOEs) and tasks to measures of performance (MOPs). Unique to the operational and tactical level decision makers, a responsibility to provide combat task guidance exists. However, only tactical decision makers are tasked to re-engage targets and utilize quick decision MMRA replanning.

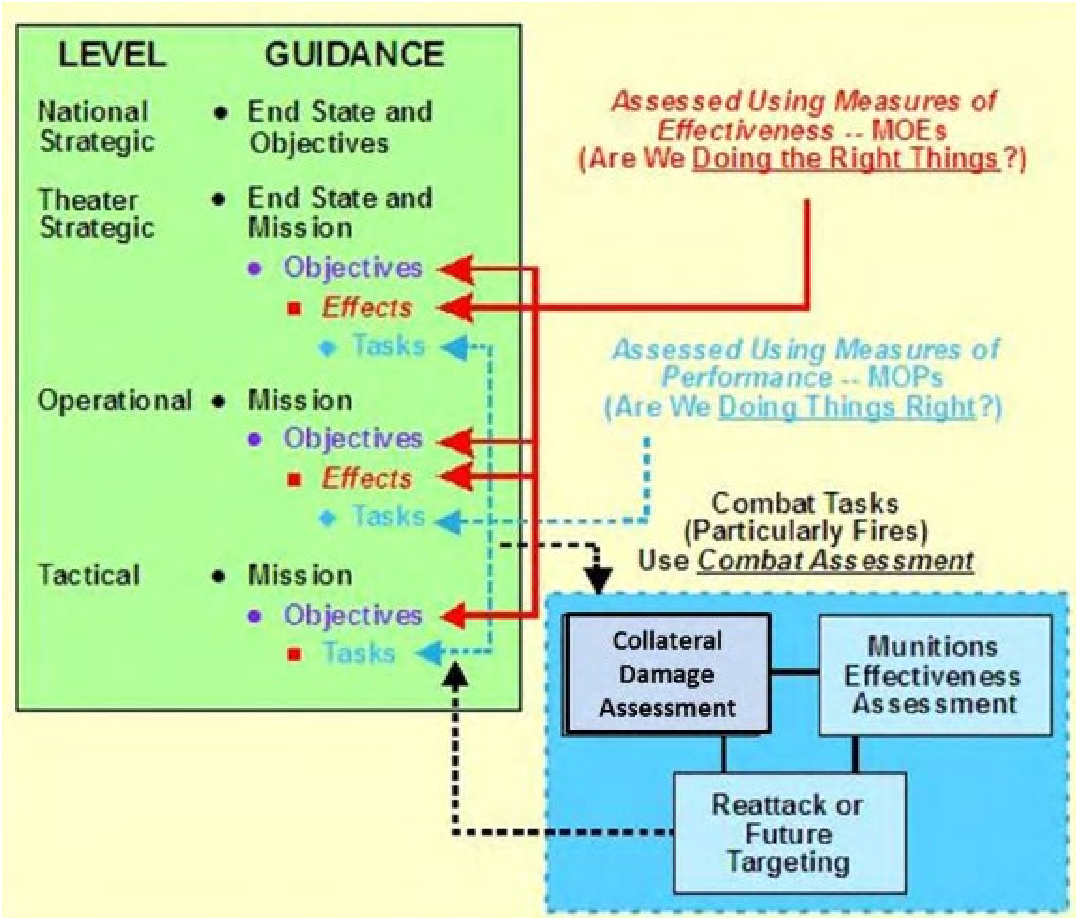

Figure 11. Strategic vs. Operational vs. Tactical. Source: Joint Targeting School (2017, 163).

The graphic in Figure 12, "Tactical Evaluation Process: MMRA Decision Complexity," depicts how MMRA is conducted over time at decision points in an operational scenario. Initial planning is conducted at t_0 which starts the process depicted in Figure 9 MMRA Process Architecture "Recycle Chart" at the "Initiate" point. The t_1, t_2, t_3, …, t_n decision points correlate to the "Decision Point Replan" yellow activity in Figure 9. Both "Initiate" and "Decision Point Replan" yellow activity blocks initiate a complete MMRA Process Flow, which is all the activities depicted inside the "Initiate" and "Decision Point Replan" continuum.

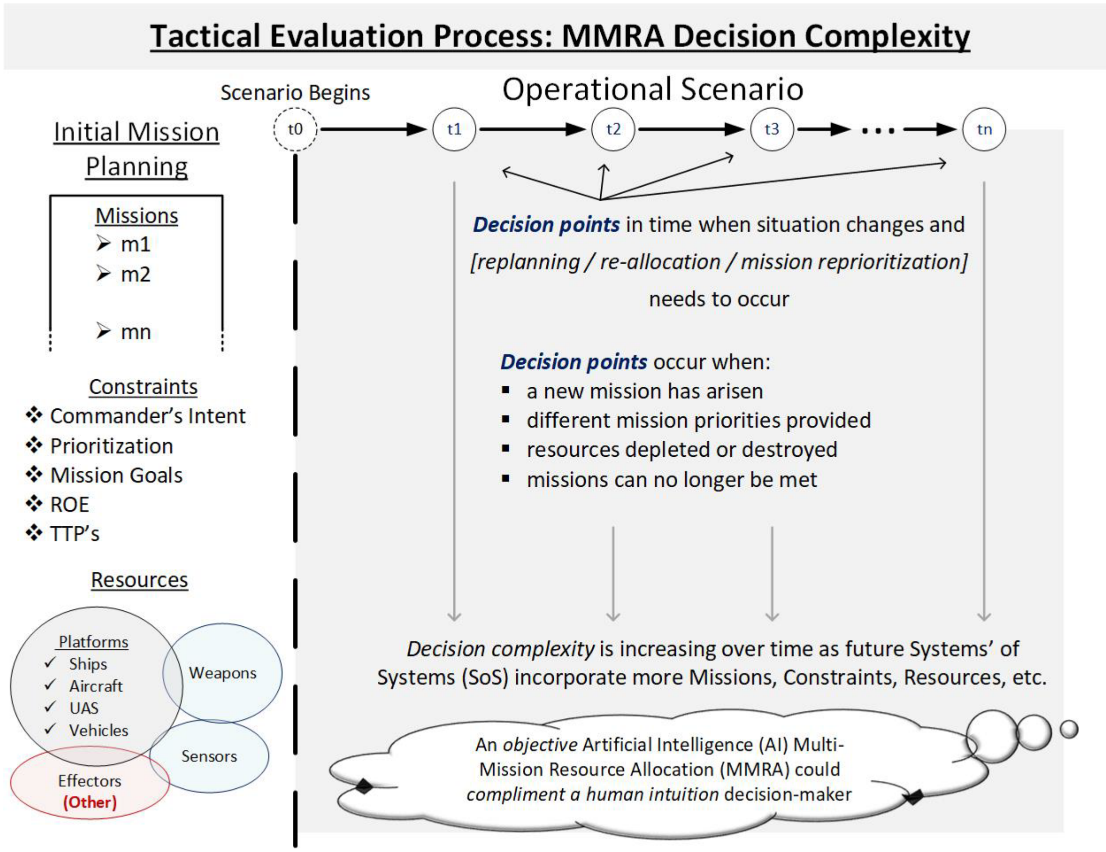

Figure 12. Tactical Evaluation Process – MMRA Decision Complexity. Source: Johnson (2022).

Decision points are commonly defined across the three MMRA use cases. However, unique storylines are applied for context. Commonly, all decision points occur when a new mission has arisen, different mission priorities are provided, resources are depleted, resources are destroyed, or the mission can no longer be met.

IV. USE CASES STUDY

A. USE CASE ANALYSIS PROCESS

For this capstone, three use cases were explored to determine how AI could aid in multi-mission resource decision-making in those scenarios. The use cases were intentionally selected for the variations in resources and complexity between them. Team AI Trio also sought to highlight the different branches of service and mission areas and explore how an AI-assisted MMRA tool could help across a variety of missions. The background of the team members also drove the choice of each use case. Team AI Trio has experience and expertise in the three specific use cases as highlighted in the team organization section of this capstone's background. For each scenario, resources were chosen based on research and the author's experiential knowledge for a typical deployment.

The missions for the use cases were selected to represent real-world deployment scenarios. The use cases also highlight the concurrent mission demands placed on the respective commanding officers that create overwhelming resource allocation conflicts. Team AI Trio approached each use case from two perspectives: scalability and complexity. Scalability was defined as: the evolution of technology over time and the resulting increase of resources available for each example. Complexity was defined as: an imagined realistic sequence of events for each scenario. Through the analysis of each, Team AI Trio garnered information on the need for an AI-enabled MMRA tool across the branches of the military. The analysis also informed how such a tool would be deployed and assist mission-planners in the operational scenarios. The focus for each use case was to determine requirements, inputs to initial planning, and re-planning considerations. Chapter V then analyzed similarities and difference between the three use cases, and explored the problem set from an SE process perspective.

B. DIRECTED ENERGY CONVOY PROTECTION

1. Overview

DE protection of land convoys was considered in this use case examining the application of the MMRA AI tool. Air defense for convoys is increasing in complexity due to the prevalence of drones and advances in RAM threats. DE is an emerging technology with potential to fill gaps in mobile counter unmanned aerial system (C-UAS) and counter rocket, artillery, and mortar (C-RAM). Many different inputs were identified that the AI-enabled MMRA system would need assist decision makers allocate these DE resources. However, even with the numerous inputs, due to the limited number of system variation and mission sets, the tool is relatively simple in complexity.

2. Background

a) The Convoy and Convoy Operations

Military convoys have been in use for many years to move supplies over land. "A tactical convoy is a military operation used to securely move personnel and cargo by ground transportation" (Beckman n.d.). Most convoy missions are "friendly-oriented (deliver what, to who, where, when, and why)" (United States Marine Corps n.d.). In addition to moving troops and equipment, intelligence collection and route clearing are implied tasks of the convoy (United States Marine Corps n.d.). The vehicles in the convoy can range "from tracked and wheeled tactical vehicles to civilian tractor-trailers" (United States Marine Corps n.d.). Table 2 shows examples of tactical vehicles and their purpose in the convoy.

Table 2. Example Convoy Vehicles. Source: United States Marine Corps; Leonardo DRS (n.d.).

Vehicle	Purpose
Medium Tactical Vehicle-Replacement (MTVR)	Troop/cargo carrier
Up-Armored HMMWV (UAH)	Security element, C2, mounted patrols
Mine-Resistant Ambush Protected (MRAP)	Lead vehicle, C2, security element
Maneuver Short-Range Air Defense (M-SHORAD)	Destroys or defeats ground and air threats using multiple kinetic effectors (direct fire and missiles)
Civilian tractor-trailers	Cargo carrier

For convoy operations to be successful, they require deliberate and careful planning (United States Marine Corps n.d.). In addition to the vehicles, there are many considerations when planning convoy operations. Considerations for route options include battlespace, organic fire support, air support, quick reaction forces, explosive ordnance disposal, casualty evacuation capabilities, and recovery assets (United States Marine Corps n.d.). The Commander's intent, which should be formed around the idea to "keep the convoy moving," must also be considered (United States Marine Corps n.d.). Another important consideration is the scheme of maneuver (SOM). Convoy operations have a combination of six elements that form the SOM: task organization, distribution of forces, route (primary & alternate), movement formations, tactical control measures, and actions on the objective (United States Marine Corps n.d.). Of these, two are particularly important for this case study:

1. Task organization

> Convoys are task organized into a Lead Security Unit, Main Body, and Rear Security Unit. The Lead Sec Unit provides security to the front and flanks of roughly the first half of the convoy and is usually tasked to "screen to the front." Similarly, the Rear Sec Unit provides security to the rear and flanks of roughly the second half of the convoy and is, therefore, tasked to "screen to the rear." The Main Body consists of the vehicles that are transporting the personnel/cargo that make up the mission and is most often tasked to "protect" that cargo. The Main Body vehicles should be located within the middle of the convoy and will supplement flank security if they are also equipped with CSWs. (United States Marine Corps n.d.)

2. Movement formations

   Open Column: "Distance between vehicles is approximately 100m-200m. This formation works best in open terrain and on roads that allow for travel at higher rates of speed" (United States Marine Corps n.d.).

   Closed Column: "Distance between vehicles is anything less than 100m. This formation works best at night, in urban areas, or in high-traffic areas" (United States Marine Corps n.d.).

As can be seen, convoy mission planning can be very complex. Different vehicles with different purposes and capabilities, resources both internal and external to the convoy, organization, and formation all increase the available options. This is assuming the convoy operations run smoothly. There are a variety of events that can add to the complexity of convoy operations. Examples of these events are shown in Table 3.

Table 3. Possible Mission Affecting Events. Source: United States Marine Corps (n.d.).

Event	**Description**
Short halt	Convoy is estimated to be stopped for 10 minutes or less
Long halt	Convoy is estimated to be stopped for more than 10 minutes
Danger area crossing	Any specific area that poses an added threat
Deliberate Recovery	Vehicle is disabled and there is no enemy contact
Hasty Recovery	Vehicle is disabled in an enemy kill zone
Unblocked Ambush	In an enemy kill zone or taking fire with no roadblock
Blocked Ambush	In a kill zone or taking fire and the road is blocked
IED Spotted	IED is identified prior to detonation
IED Detonates	IED detonates, possible casualties

b) Mobile C-RAM and C-UAS Defense Need

For convoy defense, there exists a gap for C-RAM. For land-based C-RAM there is the Land-based Phalanx Weapon System (LPWS) depicted in Figure 13 (United States Army Acquisition Support Center n.d.). However, this is meant to be stationary and could not provide C-RAM defense for a convoy that was underway (United States Army Acquisition Support Center n.d.). The M-SHORAD depicted in Figure 14 is capable of engaging UASs, however, would not be able to handle a UAS swarm type attack (Leonardo DRS n.d.). As can be seen in the conflict between Russia and Ukraine, weapons such as explosive-laden UASs and laser-guided artillery have proven to be highly effective against convoys on the front lines. In addition to the casualties on the front lines, Operation Enduring Freedom and Iraqi Freedom showed that convoys in areas that were considered secure because they were rear of the front line could still sustain heavy casualties (Thompson 2012). This leaves a need for mobile C-RAM and C-UAS defense, something DE promises to fulfill.

Figure 13. Land-based Phalanx Weapon System. Source: United States Army Acquisition Support Center (n.d.).

Figure 14. Maneuver Short-Range Air Defense. Source: Leonardo DRS (n.d.).

c) *Legacy DE Systems*

DE systems have been in development for several decades. However, thus far these DE systems have only existed as prototypes, there have been no programs of record. Two of the first DOD DE programs were the Army's Tactical High Energy Laser and the Air

Force’s Airborne Laser (ABL) which were both megawatt class chemical lasers (Shwartz 2003); (Airforce Technology 2000). Both programs started in 1996 and proved that high energy laser (HEL) systems had the ability to provide C-RAM along with cruise missile defense (Shwartz 2003); (Airforce Technology 2000). However, safety risks with the large amount of chemicals needed and the logistics associated with moving the chemicals ultimately led to the cancellation of these programs (Shwartz 2003); (Airforce Technology 2000).

d) Mobile DE System Mission Sets

The Army’s DE M-SHORAD shown in Figure 15 will be equipped with a 50kW class laser capable of C-RAM. Due to the scalable power of the HEL, the system will also be capable of operating in the grey zone and provide counterintelligence, surveillance, and reconnaissance without destroying the target (Jones-Bonbrest 2020). The powerful optics on the DE M-SHORAD will allow the collection of intelligence, surveillance, and reconnaissance (ISR) data by observing red force activity. The Army is also developing a high-power microwave (HPM) version of the M-SHORAD platform (Eversden 2021). Figure 16 shows a concept drawing of the HPM M-SHORAD. The HPM M-SHORAD will provide C-UAS capability, particularly against swarms of unmanned aerial systems (UASs) and would also be capable of counter electronics such as signal jamming (Eversden 2021). Both DE systems provide unique capabilities with the HEL systems focused on C-RAM and HPM systems focused on defeating swarms of UASs.

Figure 15. DE M-SHORAD. Source: Jones-Bonbrest (2020).

Figure 16. HPM M-SHORAD. Source: Eversden (2021).

e) Theater Use Case

For this use case, the initial situation was multiple convoys in a region that requested C-RAM and/or C-UAS protection due to red force activity and intent based on ISR data collected through various sensors and resources. The convoys consisted of various vehicles including tanks, troop transports, and supply transports along with one or more mobile DE air defense systems. An operational viewpoint one (OV-1) is depicted in Figure 17.

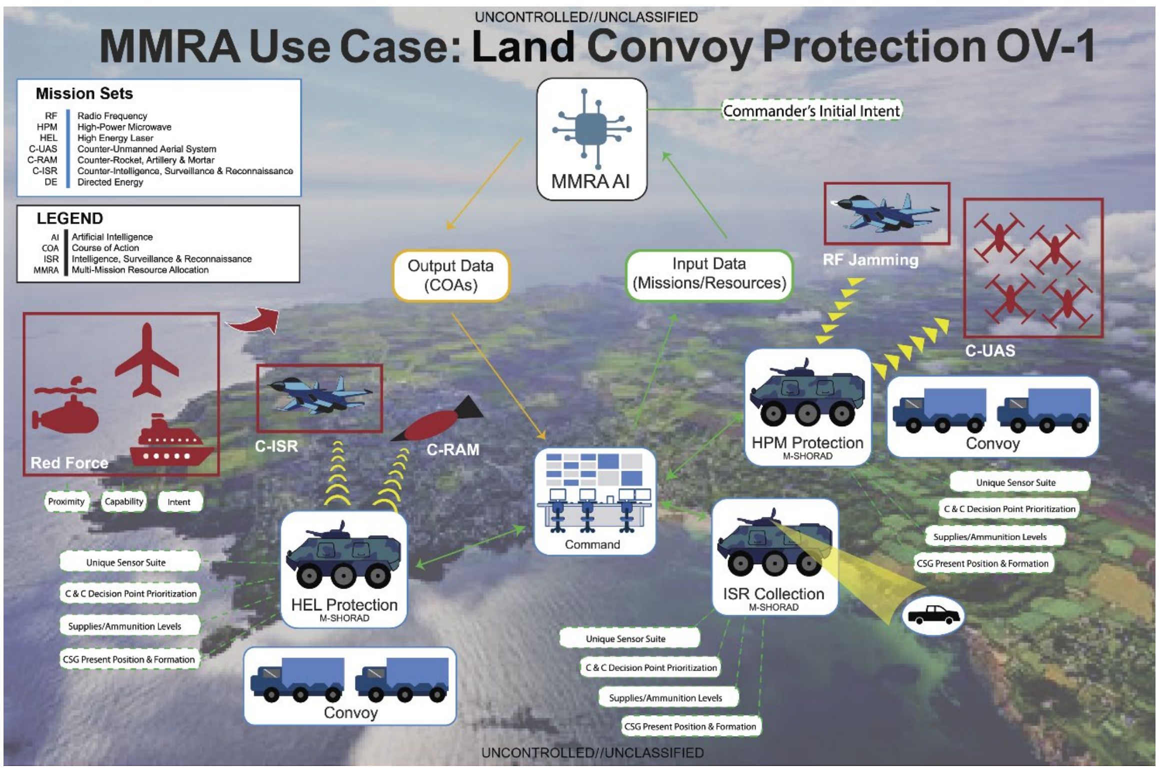

Figure 17. DE Convoy Protection OV-1

3. Tactical Decision Making

a) MMRA from a DE Perspective

While this use case was lower in complexity with respect to the other two use cases presented in this report, there were quite a few inputs identified that should be considered when determining the best allocation of resources. Table 4 lists these inputs.

Table 4. DE Resource Allocation Considerations

Inputs	**Area of Interest**	**Considerations**
Red force	Proximity to convoy route	Are they within striking range?
		Can they maneuver within striking range?
	Capability	Rocket, artillery, mortar (RAM), UAS?
	Capability	Can they disrupt the mission?
		Can they cause casualties?
	Intent	Cause casualties?
		Collect ISR?
Blue force	Convoy	Mission requirements based on expected red force capability (HEL verses HPM, number requested)?
		Asset value?
		Ability to evade red forces (speed, maneuverability, etc.)?
		Timing (can the convoy be moved up or delayed to a time when a DE system is available?)
	DE System	Can it defeat the expected threat?
		Is it available (down for maintenance, near the convoy, will it return in time for a future mission of higher importance)?
		Projected to have enough "ammo" for the mission?
WRAID	Engagement simulations	Best possible mission outcome among convoy missions based on current available DE resources and red force data?
AI Training (machine learning)	Theoretical simulations	Various possible engagements
	Historical data	Past attacks on convoys and exercise data
Environment	Weather	Performance impact due to weather conditions?
	Ground clutter	Limited field of view (buildings in urban areas, vegetation in a jungle, etc.)
Collateral/friendly damage	Personnel	Injury or death of non-combatants or friendly forces
	Buildings and equipment	Sustain laser/HPM damage
	Aircraft/Satellites	Sustain laser/HPM damage

This table shows there are numerous variables and a tremendous amount of information needed to determine the best allocation of these DE resources.

b) Decision Points

Ideally, the MMRA AI tool would constantly reassess the allocation of DE resources, however this has the potential to consume large amounts of computer processing power. This large amount of processing power may be too resource heavy and require reassessing only at major decision points. These major decision points that may call for rerunning the MMRA AI tool are:

1. Changes to DE system availability
2. Changes to convoy timetable
3. Significant changes to intelligence on red forces
4. Changes to convoy assets
5. Convoy(s) under attack

4. Analysis

a) Scalability Analysis

RAM munitions have been around for centuries. Early versions were "dumb" and were fired in numbers in hopes that some would inflict damage on the enemy. From those humble beginnings, these weapons have advanced to become more accurate and effective. This can be seen in the conflict between Russia and Ukraine where laser guided artillery is being used (Axe 2022). This improvement to accuracy leads to an increased chance of a convoy sustaining casualties if attacked. The proliferation of cheap UASs makes it even easier to locate targets and deploy laser designators.

In addition to small-scale UASs providing a means to find and target convoys, these relatively cheap UASs can be used to carry explosives. These explosive laden UASs can be used against personnel and soft targets. To attack armored vehicles within the convoy, UASs such as the Switchblade 600 can be used (Capaccio 2022). These technological advancements increase the threat to assets within a convoy and increase the scale of entities required for defending convoys.

b) Complexity Analysis

Time adds to the complexity of the elements already discussed, especially at the tactical level where the time epoch is in minutes, hours, and days. The initial scenario is run through the AI-enabled MMRA tool at t_0 which proposed the DE resource allocation for convoys A, B, and C based on the missions, constraints, resources, and available data. Convoy A is a low priority material transport convoy which will be traveling through mostly an urban environment that is known to have red forces that use UASs. It is allocated two HPM systems. Convoy B is a high priority troop and equipment convoy that will be traveling through a mix of urban and mountainous environments with a high amount of red force artillery activity. This convoy is allocated one HPM system and three HEL systems. Convoy C is a medium priority material convoy traveling mostly open terrain. It is allocated two HEL systems. Two HPM and two HEL systems remain behind as base defense and serve as emergency reserves.

At some point in the future after the convoys have set out, it was discovered that the red force mortar activity in the vicinity of convoy A was heavier than expected. Convoy A requested HEL systems to assist with protecting the convoy. This is considered decision point t_1 which called for the MMRA AI tool to be run to check if changes in the resource allocation should be made. In this case the MMRA tool quickly calculated COAs based on all factors available (especially resource time to location) and suggests reallocation of one HEL system from the base reserve.

At decision point t_2, convoy B is reporting less than expected red force activity while convoy C is experiencing higher red force activity and lost one of its HEL systems due to red force fire. Considering the priority of the missions and probability of mission success, the MMRA tool suggests reallocating one HEL system from convoy B to convoy C. The MMRA tool also took into consideration the time for the DE system to reach the convoy. The amount of time required to adjust to this new allocation is a key factor. If resources can be reallocated in minutes, that might be feasible, given the tactical situation. Without this consideration, the MMRA tool may recommend a set of allocations that would take too much time to implement. Again, time adds complexity to the operating challenge.

After the convoys had completed their missions, three new convoy missions were planned. Information on an additional two HPM and two HEL systems scheduled to be deployed to the base in the coming days marks decision point t_3. With this new information, the MMRA tool recommended a shift in the execution timing of the future COAs due to significant increase in mission success probabilities from simulations from the wargaming tool. However, in this case the commander's intent for one of the future convoys required the COA for that convoy to be executed at the planned time. As one can see, over time, resource allocation becomes increasingly complex.

Table 5. DE Convoy Protection Complexity Analysis Decision Points

Decision Point	**DE Convoy Protection Scenario Event Resource Allocation**
t_0	In reserve: HPM: 2, HEL: 2 Convoy A: HPM: 2, HEL: 0 Convoy B: HPM: 1, HEL: 3 Convoy C: HPM: 0, HEL: 2
t_1	In reserve: HPM: 2, HEL: 1 Convoy A: HPM: 2, HEL: 1 Convoy B: HPM: 1, HEL: 3 Convoy C: HPM: 0, HEL: 2
t_2	In reserve: HPM: 2, HEL: 1 Convoy A: HPM: 2, HEL: 1 Convoy B: HPM: 1, HEL: 2 Convoy C: HPM: 0, HEL: 1 (along with two damaged)
t_3	In reserve: HPM: 4, HEL: 3 Convoy A: HPM: 2, HEL: 1 Convoy B: HPM: 1, HEL: 2 Convoy C: HPM: 0, HEL: 1

C. FVL / FLRAA

1. Overview

The aviation support use case explores one of the U.S. Army's many aviation platforms in legacy and future systems, the UH-60 Blackhawk and FLRAA, respectively. Both systems fulfill the U.S. Armed Forces utility-class helicopter capability set, as defined in U.S. Army Field Manual (FM) 1–113. Further, both systems provided a suitable system to decompose the MMRA problem set. It was verified through DOD architecture framework (DODAF) perspectives and systems decomposition that the resource allocation needs of a legacy UH-60 aircraft are complex and require skilled human decision-making. Further, it was validated through a scalability analysis and complexity analysis that the initial and replanning demands are increasing over time. The near-term U.S. Armed Forces needs for an AI-assisted MMRA tool may have a trade space with a relatively small increase of 15% from legacy to future resource allocation complexity. However, the overall SoS complexity is considerably more interconnected and only shows trends of increasing demands. Future research is strongly encouraged to future decompose the AI-assisted MMRA aviation use case, such as Human Systems Integration (HSI), cyber security and computer hardware specifications for aircraft weight savings.

2. Background

a) Legacy Utility-class Helicopter

The UH-60 Blackhawk family of helicopters as depicted in Figure 18 has been a beloved aircraft of the U.S. Military and U.S. foreign military partners for many decades. Since its induction into the U.S. Army in 1979, the UH-60 has served a broad range of missions sets in the utility class helicopter capability set.

Figure 18. UH-60 Blackhawk. Source: PEO Aviation (2020).

As depicted, the Blackhawk has multiple resource needs to meet the utility class mission sets. Considerations that formulate mission inputs across all aviation mission sets include supply levels, baseline capabilities, command and control decision prioritization, aerial battalion pattern, and enemy (red) force intelligence, as depicted in Figure 19. Although red force intelligence is fluid, the red force inputs for an AI MMRA have been restricted to proximity/asset positions, capability/threat, and intent. Less fluid and ambiguous is the USG and allied (blue) force conditions for this study. Table 6 organizes the legacy UH-60 utility class helicopter MMRA inputs into these generic categories, red force, blue force, WRAID, and AI Training.

Table 6. Legacy Aviation Resource Allocation Considerations

Inputs	**Area of Interest**	**Considerations**
Red force	Proximity	Are they within striking range?
		For what duration are they within range?
		Are red forces mobile/stationary? Ground/ air?
		Red force targets for blue force in range?
	Capability	Weapons, Strategic Assets to target?
		Can they disrupt the mission?
		For how long/supplies can they disrupt?
		Can they cause casualties?
	Intent	Cause casualties?
		Stall/distract? Active denial?
		Collect ISR?
Blue force	Aerial formation	Overall Mission Requirements (which aircraft support which functions)
		Strategic Positioning & Flight pattern
		Ability to defend against red forces (unit positioning, maneuverability, Aircraft Survivability Equipment (ASE))?
		Timing considerations (how long to move the formation into position? Pre-flight spin-up?)
		Can it out run, camouflage from, or defeat the expected threat?
	Outfitted Variants	Availability (range with current supplies, operational status, proximity to command and control (C&C)/target, maintenance downtime considerations)?

Inputs	Area of Interest	Considerations
		Medical evacuation (MEDEVAC) / special operations command (SOCOM) capability mission requirements?
		Outfitted weapons capabilities
		Does the theater/mission permit reliable communications and assured positioning?
		Intended overall mission outcome among unit missions based on current available resources and red force data?
WRAID	Engagement simulations	Various possible engagements
AI Training (machine learning)	Theoretical simulations	live virtual constructive (LVC) data inputs
		Aviation SoS weapons capabilities data
	Historical data	Specific topological/area considerations
		Past attacks on aerial formations
Environment	Weather	Performance impact due to weather conditions?
	Ground topology	Limited field of view (buildings in urban areas, vegetation in a jungle, etc.)
Collateral/friendly damage	Personnel	Injury or death of non-combatants or friendly forces
	Buildings and equipment	Sustain damage
	Aircraft/Satellites	Sustain damage

The UH-60 Blackhawk has served as the U.S. Military's premier utility-class helicopter for decades through diligent life cycle engineering effort. Since entering the U.S. Army aviation fleet in 1979, the UH-60 family has undergone half a dozen variants, a dozen special purpose spin-offs, and nearly three dozen foreign military sale models (PEO Aviation 2020). Across so many variations, maintaining a modular platform that is free of obsolescence and equipped for a growing set of technology insertions has been increasingly difficult.

However, it has become increasingly necessary to revise the baseline for the platform utility-class helicopter for the near-future technology insertions. The Army's Program Executive Office Aviation seeks to enable future Joint U.S. Military operations through their FVL programs (Geerges, Rugen, and Barrie 2021). The FLRAA program is the Army’s future utility-class helicopter, which will enable cheaper sustainment, farther reach, faster airspeeds, and increased personnel seating.

b) Utility-class Assault Helicopter Mission Sets

The need for a FLRAA intends to fill the FVL utility-class helicopter mission sets. A helicopter is considered utility class if it can transport a small team of fully equipped personnel to support a range of roles, such as internal/external lift, combat assault, MEDEVAC, C&C, disaster relief, aerial firefighting, search and rescue, special operations, and very important person transport. Utility class helicopters are generally deployed in multiples with various aerial and ground supports. The collective team that supports these utility class missions sets can be considered the aerial formation and require a system of systems resource allocation network.

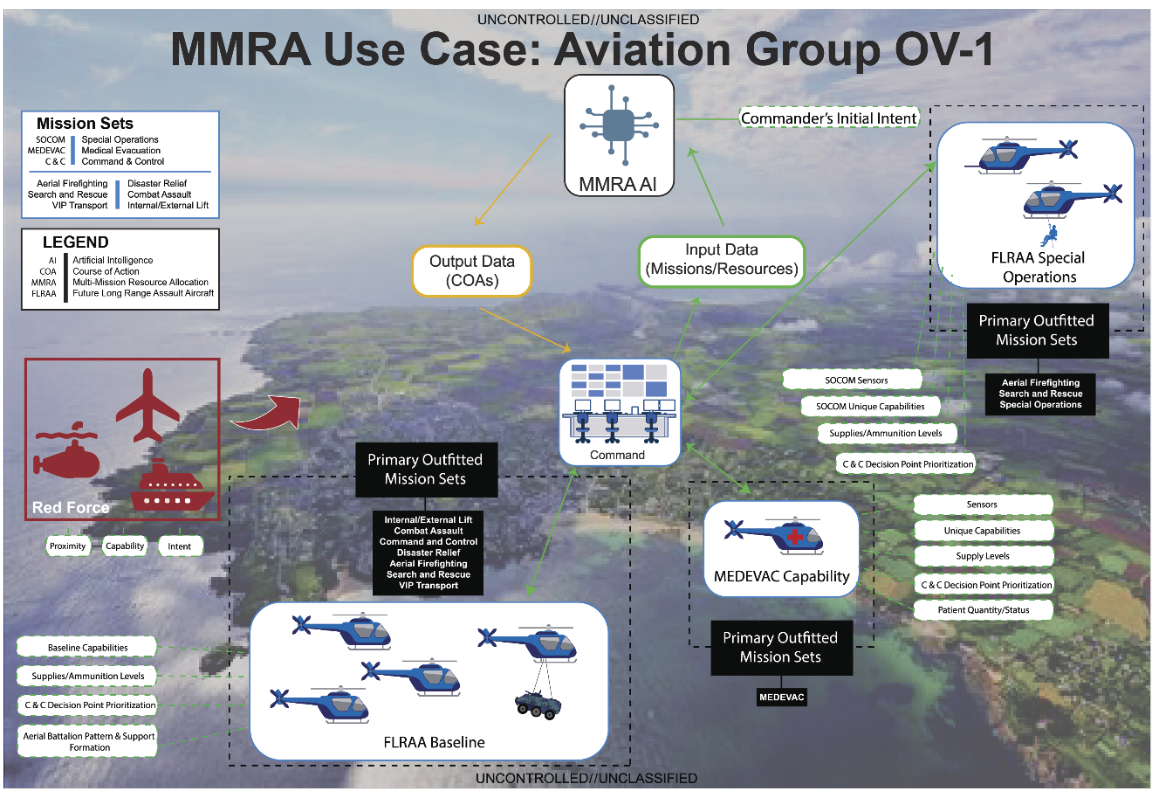

Figure 19. MMRA Use Case: Aviation OV-1

The above OV-1 is a DODAF for the aviation use case. Specifically, the aviation use case examines the FVL and FLRAA mission sets. Via capability set 3, the U.S. Army intends for FLRAA to fill the utility-class helicopter mission sets defined in Army doctrine (FM 1-113 Army FM: Utility and Cargo Helicopter Operations). As categories these mission sets are performed on the baseline, variant, and special use platforms. The baseline, MEDEVAC and SOCOM variants are commonly deployed utility-class aircraft in the fleet today. Figure 20 displays the HH-60 MEDEVAC variant of the UH-60 utility-class helicopter. Within the OV-1 shown in Figure 19, these common variants are interacting with the MMRA AI via the previously discussed MMRA Process Architecture "Recycle Chart." Input data for the MMRA Process Architecture are envisioned to be relayed directly from the aviation command, commonly also ground control. From command, the aerial pattern of FLRAA variants on concurrent or joint missions receive MMRA Output COAs.

Figure 20. HH-60 Medical Evacuation (MEDEVAC). Source: Military Aerospace Electronics (2020).

It is important to note here that the MMRA AI is not envisioned to be deployed to an aviation platform or forward position. Previously discussed inputs for the MMRA AI are blue force sensitive information, and serious security considerations must first be explored. An area of future research for this study was identified to include cyber security. If security considerations for maintaining sensitive MMRA AI input data are resolved, then the future MMRA AI aviation use case may consider realizing faster COA outputs in a forward position.

c) U.S. Army FVL FLRAA Down-select Alternatives

The FVL FLRAA down-select alternatives to represent the Army's future medium lift, utility helicopter are alluring. Many factors are considered when two comparable technology alternatives are in competition. However, the Army has identified its top three objective capability needs to be increased speed, range, and personnel transport payload.

Figure 21. Sikorsky Boeing SB-1 Defiant X. Source: Lockheed Martin (2022).

Figure 22. Bell V-280 Valor. Source: Bell (2022).

Both aircraft alternatives are currently flight worthy with varying levels of technology maturation in subsystems. Overall, the Bell V-280 Valor has demonstrated far greater capability as shown in Table 7. Unfortunately, Sikorsky Boeing experienced severe setbacks in initial testing prior to 2019 and has not yet demonstrated threshold capability levels (Gill 2021). However, Sikorsky Boeing has projected technology maturation goals as shown in Table 8. Table 7 serves as a visual for comparable tilt-rotor aircraft technology such as the CV-22 Osprey, a legacy aircraft similar to the V-280, shown in Figure 22. Table 8 serves as a visual for comparable compound and rigid dual-coaxial aircraft technology such as the AH-56 Cheyenne and Russian Kamov KA-52 Alligator. The vertical flight capabilities of the first practical helicopter, Sikorsky's VS-300A, are included as an anchoring reference for rotorcraft technological evolution.

Table 7. Comparable Tilt-Rotor Aircraft Technology. Source: Bell; AFSOC Public Affairs (2022; 2020).

	True Airspeed	**Range**	**Payload**
V-280 Valor	322.2 mph (280 kn)	575-920 mi (500-800 nm)	14 (seated personnel); 4 crew
CV-22 Osprey	333.2 mph (280 kn)	575.4 mi (500 nm)	24 (seated personnel)

A comparative analysis of the V-280 Valor is best made with its parent company legacy, the Bell Boeing V-22 Osprey. The V-22 is a 21st century aircraft with multiple proven capability sets. Due to its engineering and tilt-rotor design, the V-22 touts an impressive speed, range and payload which has successfully been emulated in Bell's V-280 smaller profile. Unfortunately, these advanced capabilities set the U.S. Air Force back approximately $90 million per unit (AFSOC Public Affairs 2020). Further, the V-22 is infamous for high maintenance cost, particularly due to the novel rotorcraft technology and numerous moving parts. The parent company Bell has long understood this perception, sensitivity to cost and has reiterated across multiple platforms that the V-280 Valor has taken the lessons learned from the V-22. To reaffirm this, Bell has conducted flight test operations well in excess of the U.S. Army's requirements and their competitor Sikorsky Boeing.

Table 8. Comparable Compound and Dual-Rotor Aircraft Technology. Source: Lockheed Martin; Weapons Detective; Pfau; Sof (2022; 2020; 2018; 2017).

	True Airspeed	**Range**	**Payload**
SB-1 Defiant	242~[287] mph (211~[250] kn)	~[526] mi ([848] km)	12 (seated personnel); 4 crew
AH-59 Cheyenne	243.9 mph (212 kn)		0 (Attack/Recon a/c); 2 pilots
Ka-52 Alligator	186.4 mph (300 km/hr)	285.8 mi (460 km)	0 (Attack/Recon a/c); 2 pilots

A comparative analysis of the SB-1 Defiant X is difficult to be made due to limited proven flight data, the novel combination of multiple rotorcraft technologies, and differences in aircraft mission sets. Two similar aircraft to the SB-1 Defiant are the AH-59 compound helicopter utilizing a rear push propeller and the KA-52 rigid dual-coaxial helicopter. Contrary, the AH-59 and KA-52 are classified as Attack and Reconnaissance aircraft, per U.S. Army Regulation (AR) FM 1-112 l: Attack Helicopter Operations. Albeit, the SB-1 Defiant is designed to meet the capability sets defined by medium lift Utility aircraft, per AR FM 1-113 Army FM: Utility and Cargo Helicopter Operations.

Regardless of the contractual down-selectee, both materiel solutions provide an exceptional cutting-edge FVL aircraft to the U.S. Armed Forces and allies. Both down-select alternatives provide similar future capability sets and have been generalized for the purpose of this capstone report.

3. Tactical Decision Making

a) MMRA from an Aviation Perspective

The aviation use case has a robust historical context. However, future resource allocations can be categorically compared to better understand future solution sets. In the context of tactical decision making, a need exists to understand changes from legacy MMRA to modern. Understanding these aviation inputs for classical human-centered decision making will guide future AI-complimented MMRA solution sets. There were several inputs to consider when determining the best allocation of resources. Table 9 lists these inputs that must be considered.

Table 9. FLRAA Aviation Resource Allocation Considerations

		Legacy Utility-class Helicopter	**Future-specific Resources**
Red force	Proximity	Are they within striking range?	Future, near peers have over-the-horizon striking
		For what duration are they within range?	Speed is increasing, thus allowable response time is decreasing
		Are red forces mobile/stationary? Ground/air?	Future peers include cyber attacks
		Red force targets for blue force in range?	Unknown future condition
	Capability	Weapons, Strategic Assets to target?	Modern society has a robust commercial base which doubles as militia assets

		Legacy Utility-class Helicopter	Future-specific Resources
		Can they disrupt the mission?	Survivability equipment trending percentile effectiveness
		For how long/supplies can they disrupt?	Potentially no change over time, mass-manufacturing is an industrial era capability
		Can they cause casualties?	Unknown future condition
	Intent	Cause casualties?	Unknown future condition
		Stall/distract? Active denial?	Potentially increase over time as attack domains expand to Cyber
		Collect ISR?	Unknown future condition
Blue force	Aerial formation	Overall Mission Requirements (which aircraft support which functions)	Potentially no change or decrease, FLRAA also to support variants with emphasis on modularity
		Strategic Positioning & Flight pattern	Potentially more MMRA alternatives with UAS teaming
		Ability to defend against red forces (unit positioning, maneuverability, ASE)?	An increase of ASE systems is needed over time to meet new threats.
		Timing considerations (how long to move the formation into position? Pre-flight spin-up?)	Potentially no change. However, FLRAA will have twice the range and speed as legacy
		Can it out run, camouflage from, or defeat the expected threat?	Unknow future condition
	Outfitted Variants	Availability (range with current supplies, operational status, proximity to C&C/target, maintenance downtime considerations)?	Mission sets such as MEDEVAC can participate in more trade-off with extended range, faster speeds at higher altitudes

		Legacy Utility-class Helicopter	Future-specific Resources
		MEDEVAC / SOCOM capability mission requirements?	Expanded alternatives with enhances and improved comms
		Outfitted weapons capabilities	Potentially decreasing on aircraft as technology in missiles and space expand, and speed/range are prioritized
		Does the theater/mission permit reliable communications and assured positioning?	Likely increasing MMRA consideration in near-peer engagements
		Intended overall mission outcome among unit missions based on current available resources and red force data?	Unknown future condition
WRAID	Engagement simulations	Various possible engagements	Future scenario is considerably more complex, permutations are exponential
AI Training (machine learning)	Theoretical simulations	LVC data inputs	Unknown future condition. Will include empirical analysis.
		Aviation SoS weapons capabilities data	Unknown future condition
	Historical data	Specific topological/area considerations	Unknown future condition, potentially more diverse than previous decades wars in arid, dessert scape
		Past attacks on aerial formations	Unknown future condition

As shown above, many categories under consideration for MMRA inputs are expanding over time.

b) Decision Points

The decision points across all use cases, aviation, DE convoy, and CSG follow the same generic decision point criteria. As a simplifying assumption, the MMRA AI replanning cycles were assessed at storyline points instead of incremental temporal sampling points. This assumption was made as a derivation of the AI black box study simplification. By focusing on storyline decision points, our study was better able to conduct the intended SE input and output systems analysis required to decompose the MMRA problem set.

A unique subset of the aviation storyline points reside within the generic decision point criteria. If any of the below storyline points occurred throughout an aviation mission, then the resulting MMRA decision would be classified as mission critical. These major decision points that by criteria would call for rerunning the MMRA AI tool are:

1. Loss of comms
2. Loss of fuel efficiency / management
3. Unexpected / inaccurate red force intelligence on proximity, capability, or intent
4. Commander's initial intent changes

4. Analysis

a) Scalability Analysis

The below scalability analysis sought to display the aviation problem set from a static t_0, initial planning perspective. Effort was applied to quantitatively assess the percentile increase of the resources requiring allocation between the legacy UH-60 Blackhawk and future FLRAA aviation platforms. Table 10 follows the afore mentioned resource allocation table formats to consolidate enabling capability trends. It was proposed, that if the scaled trend is increasing then the future resources allocation needs are becoming more objectively complex. As decision makers are pressed to the human limit, an opportunity to augment with machine learning AI exists.

Table 10. FLRAA Aviation Resource Allocation Considerations

		Legacy Scale	Future Scale	Future Trend
Red force	Proximity	5	7	Increasing
		5	7	Increasing
		5	7	Increasing
		5	5	Unknown
	Capability	5	7	Increasing
		5	3	Decreasing
		5	5	No change
		5	5	Unknown
	Intent	5	5	Unknown
		5	7	Increasing
		5	5	Unknown
Blue force	Aerial formation	5	3	Decreasing
		5	7	Increasing
		5	7	Increasing
		5	5	No change
		5	5	Unknown
	Outfitted Variants	5	7	Increasing
		5	7	Increasing
		5	7	Increasing
		5	7	Increasing
		5	5	Unknown
WRAID	Engagement simulations	5	7	Increasing
AI Training (ML)	Theoretical simulations	5	5	Unknown
		5	5	Unknown
	Historical data	5	5	Unknown
		5	5	Unknown
Scalability Instantiations		130	150	

Based on the aviation scalability analysis, a 15% increase in static state MMRA exists between the legacy and future system. A consideration for future MMRA study may include a HSI analysis to deep-dive the aviation decision makers demands. Potentially, the resource allocations decision process may be manageable for some near future with effective HSI management. Alternatively, if a MMRA AI was developed an HSI analysis may greatly compliment the integration of machine and human teaming. This scalable increase makes resource allocation an ever-increasing challenge.

b) *Complexity Analysis*

Complimentary to the scalability analysis, the complexity analysis was a dynamic study of the MMRA replanning cycle. This analysis sought to study the story points over a temporal epic as part of the tactical decision replanning. Time was observed at decision points t_1, t_2, t_n. Though previously discussed, the Tactical Evaluation Process: MMRA Decision Complexity graphic is displayed in Figure 23 for reference.

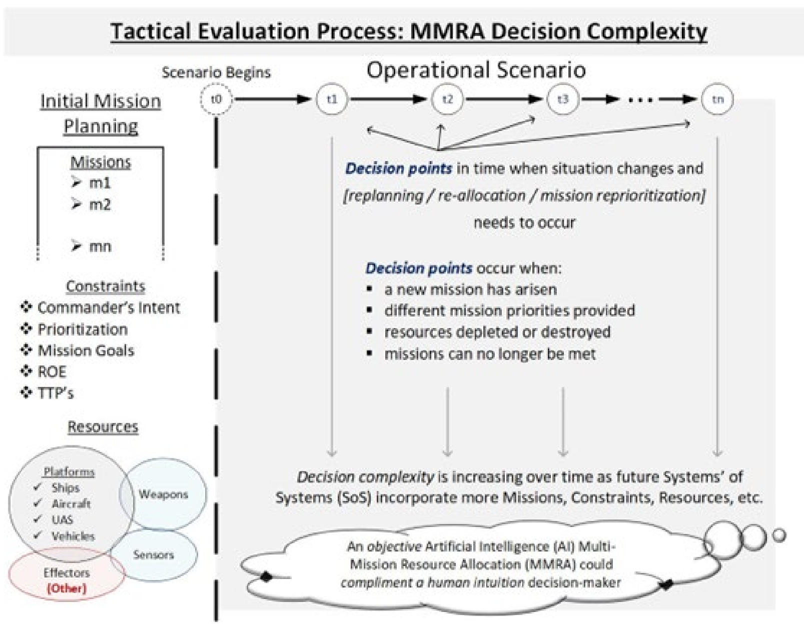

Figure 23. Tactical Evaluation Process – MMRA Decision Complexity. Source: Johnson (2022)

The aviation complexity analysis was conducted as a thought experiment placed in a fictional storyline. The below storyline decision points were envisioned in a dynamic simulation.

t_0: Start mission

t_1: The FLRAA pilot sees a flare in the distance [Potentially, a new mission has arisen]

t_2: Error displays on the pilot's dashboard [Potentially, the mission can no longer be met]

At the beginning of the mission, t_0, the MMRA AI was initially ran via the MMRA process architecture. At this time, the aviation command was provided an objective COA to best suit the present scenario. It was at this time that the human decision maker in the loop made the final decision to execute an individual MEDEVAC FLRAA for a medium range, uncontested mission.

During early flight, the FLRAA aircraft pilot relays to command that they have seen a rescue flare in the distance. At this time, the aviation command distinguishes this relay as a MMRA decision point: a new mission has arisen. The command rerun the MMRA AI, which follows the MMRA process architecture "Recycle Chart" and outputs a best scenario COA. Since the MMRA AI is centrally positioned, it is aware of the second MEDEVAC FLRAA scheduled to perform a non-critical patient transport later in the day. Considering all inputs, the MMRA AI outputs a COA to maintain initial mission and reallocate other resources for the potential new mission ISR. The human in the loop receives this COA and decides to proceed.

Later during the return flight, the FLRAA aircraft pilot relays to command that they are experiencing a fault code and may have a non-critical issue. At this time, the aviation command again distinguishes this relay as a MMRA decision point: potentially the mission can no longer be met. The command representative thus reruns the MMRA. Due to the MMRA AI's input of historical data to include maintenance work logs, the objective COA is determined to maintain flight back to command and reallocate to unscheduled maintenance immediately following. The human in the loop receives this COA and has a general uneasiness as they are unfamiliar with the criticality of the error code. Currently, the human in the loop rereviews the MMRA AI's associated COA statistical confidence risk assessment. They still have uneasiness and call a trusted contact in the maintenance shop for validation before deciding to proceed to successfully conclude the mission. Table 11 lists the decision points for the aviation scenario.

Table 11. Aviation Support Complexity Analysis Decision Points

Decision Point	Aviation Support Scenario Event Resource Allocation
t_0	Start mission. MEDEVAC variant aircraft, full fuel levels.
t_1	The FLRAA pilot sees a flare in the distance [Potentially, a new mission has arisen]. MEDEVAC variant aircraft, depleting fuel stores, non-critical patient on-board.
t_2	Error displays on the pilot's dashboard [Potentially, the mission can no longer be met]. MEDEVAC variant aircraft, heavily depleting fuel stores, non-critical patient on-board, potential aircraft failure.

The above fictional aviation storyline is an oversimplification of the real-world scenarios that MMRA decision makers face every day. As the operational scenarios become more difficult and complex, the military historically relies on trust overcome. An area of future research may bundle HSI analysis with building trust with AI and computer aided partners. Though not needed soon, the aviation space is becoming increasingly complex especially with UASs and modern engagement policies.

D. CARRIER STRIKE GROUP

1. Overview

The CSG is another use case that the team studied for the application of AI-enabled MMRA tool. A CSG is comprised of ships, a submarine or two, and aircraft working toward a common main goal. Most platforms are capable of supporting several missions, creating conflict when the same resources are allocated to competing missions. The varied capabilities also lead to different resource allocations for each ship, submarine, and aircraft. On any given day, the individual units of the CSG will have a particular mission set and unique resource contributions. The following sections explore the CSG composition, individual unit requirements, how AI-assisted MMRA might assist in the resource planning for a CSG, and decision points for re-planning specific to the CSG scenario.

2. Background

a) Legacy Naval Ships: A Centennial of the Aircraft Carrier

The first carrier was commissioned on March 20, 1922, as an experiment (United States Navy 2019). The strategic advantage of the aircraft carrier was quickly identified, and the CSG was born. Since that time, the CSG has been the cornerstone of the United States Navy (USN) mission. Rear Admiral James P. Downey remarked when he assumed command of the program executive office of aircraft carriers on June 21, 2019, that "The aircraft carrier is our [U.S.] Navy's centerpiece, our flagship, and a constant reminder to the rest of the world of our enduring maritime presence and influence. These ships touch every part of our Navy's mission to project power, ensure sea control, and deter our adversaries" (United States Navy 2019).

b) CSG Mission Sets

As the name implies, the CSG centers on the aircraft carrier and air dominance in a given mission location. The USN website on the aircraft carrier states that "aircraft carriers support and operate aircraft that engage in attacks on airborne, afloat and ashore targets that threaten free use of the sea and engage in sustained power projection operations in support of [U.S.] and coalition forces" (United States Navy 2021). The CSG is comprised of many units that not only support the air power of the carrier, but also specialize in other missions to support the interests of the United States. Each ship in the CSG has a range of specialized missions it can execute. The cruisers and destroyers perform anti-air warfare (AAW), anti-submarine warfare (ASW), anti-surface warfare (ASUW), strike (STK), and ballistic missile defense (BMD). The submarine mission includes ASW, ASUW, STK, plus the added mission sets of intelligence (INTL) gathering, reconnaissance (RCN), and surveillance (SV). The supply ship (T-AO) serves the CSG with a primary mission set of emergency response (ER) and resupply (RESUP). Together, the ships that make up a CSG and the 10 basic mission sets they execute bring the full power of the USN all around the globe. Table 12 lists the specific resources and mission sets for each unit, and Table 13 lists example mission sets of the CSG SoS.

Table 12. CSG Resources Mapped to Missions

Resource	Missions
Aircraft Carrier (CVN)	AAW, aircraft support (ACS), ER, ASUW
Cruiser (CG)	AAW, ASW, ASUW, STK, BMD
Destroyer (DDG)	AAW, ASW, ASUW, STK, BMD
Submarine (SSN)	AAW, ASUW, STK, INTL, RCN, SV
Fleet Replenishment Oiler (T-AO)	ER, RESUP

Table 13. Example CSG Mission Sets

CSG	Mission
CSG-1	"To conduct carrier air warfare operations and assist in the planning, control, coordination and integration of air wing squadrons in support of carrier air warfare." (United States Navy n.d.)
U.S. Second Fleet (CSG-2, CSG-8, CSG-10, CSG-12)	"Command and control mission-ready forces to deter and defeat potential adversaries. Defend maritime avenues of approach between North America and Europe. Strengthen our ability to operate with allies and partners in competition and conflict." (United States Navy n.d.)
CSG-4	"trains and delivers combat-ready naval forces to U.S. Fleet Forces Command and U.S. 2nd Fleet, which are capable of conducting full-spectrum integrated maritime, joint and combined operations in support of U.S. national interests." (United States Navy n.d.)

c) Theater CSG Use Case

For this use case, a forward deployed CSG with the following ship make up was considered: an aircraft carrier (CVN), three guided missile destroyers (DDG), two cruisers (CG), one Virginia-class submarine (SSN), and a fleet replenishment oiler (T-AO). The scenario also included all the resources associated with each vessel. Examples of those resources are: personnel, sensors, armament, aircraft, and specific capabilities for the given mission of each vessel and resource therein. Figure 24 depicts the complexity of the CSG scenario.

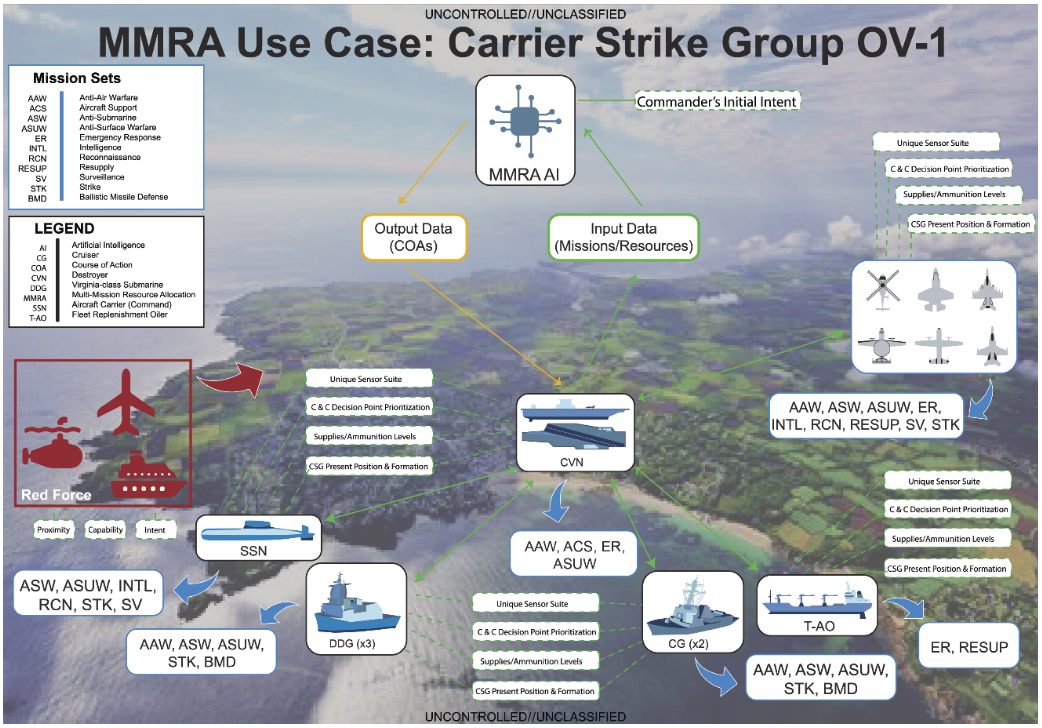

Figure 24. CSG Scenario OV-1 Diagram

The resources of the CSG must be allocated to ensure the missions are prioritized and fulfilled. With the duplication of certain mission sets, unit assignments can be flexible if a given ship is unavailable due to RESUP needs. However, both the SSN and the T-AO perform unique functions that must take priority if required. In contrast to the first two use cases examined, the CSG mission sets are scoped over days, weeks, and months. MMRA must consider the geographical disbursement of resources and minimum time limits to reposition assets.

3. Tactical Decision Making

a) MMRA from a CSG Perspective

The CSG use case was the most complex that Team AI Trio explored for this capstone. Within a CSG, there are thousands of resources which are required to perform the multiple mission sets of the group. Table 14 lists the resource allocation considerations and depicts the complexity of the MMRA problem set for a CSG.

Table 14. CSG Resource Allocation Considerations

Inputs	**Area of Interest**	**Considerations**
Red force	Proximity to CSG	Are they within striking range?
		Can they maneuver within striking range?
		Red force targets for blue force in range?
	Capability	Weapons, Strategic Assets to target?
		Can they disrupt the mission?
		Can they cause casualties?
	Intent	Cause casualties?
		Collect ISR?
Blue force	CSG	Overall Mission Requirements (commander's intent)
		Strategic Positioning
		Ability to defend against red forces (unit positioning, maneuverability, CSG defense)?
		Timing considerations (how long to move the CSG into position?)
		Can it defeat the expected threat?
	Individual Units	Availability (RESUP needs, operational status, proximity to CVN, will it return in time for a future mission of higher importance)?
		Unit Special Mission Requirements?
		Weapons capabilities? Weapons RESUP.
		Best possible overall mission outcome among unit missions based on current available resources and red force data?
		Sensor outputs
WRAID	Engagement simulations	Various possible engagements
AI Training (ML)	Theoretical simulations	LVC data inputs
		CSG SoS weapons capabilities data
	Historical data	Past attacks on CSG
Environment	Weather	Performance impact due to weather conditions?
	Ocean effects	Limited detection range of sensors (ducting effects)
Collateral/friendly damage	Personnel	Injury or death of non-combatants or friendly forces
	Other units	Sustain accidental friendly fire
	Aircraft	Sustain accidental friendly fire

Within the table above, each consideration in the third column encompasses many data points that go into the MMRA AI system. As an example, a single CG within the group could have two helicopters, multiple radars providing inputs on enemy forces, 122 missile cells capable of a mix of air defense, land attack and ship attack missiles, Harpoon missiles, torpedo tubes, Phalanx Close-In Weapons System (CIWS), multiple gun systems, and electronic warfare (EW) capability. At a given time, the inputs to the MMRA AI could easily number in the thousands.

b) Decision Points

Initially, the CSG commander would employ the MMRA AI tool when high level mission requirements are set. With the complexity of resources involved in the CSG use case, replanning with the MMRA AI tool would be required when changes to resource availability reach a threshold that impacts commander's intent. Additionally, a significant change in red force inputs would also necessitate replanning of CSG resources. These decisions points are:

1. Changes to individual unit availability (becomes available/unavailable)
2. Significant changes to intelligence on red forces (change in proximity, capability, or intent)
3. Red forces attack and deplete resources
4. Emergency operations (within the CSG, external to the CSG, natural disaster aid response)

With individual unit RESUP requirements, regular MMRA AI replanning would likely occur every five to seven days. The other decision points would occur on an ad hoc basis.

4. Analysis

a) Scalability Analysis

Over time, the mission set of each unit in a CSG has increased. Consider the destroyer's role in the CSG. The replacement of the Charles F. Adams class (DDG-2) with the Arleigh-Burke (DDG-51) class destroyer program brought new resources and capabilities to the CSG. In addition, the Arleigh-Burke class has been significantly upgraded three times in the lifetime of the program. Each new variant added resources and capabilities to the platforms (SEA 00D 2021). The original mission set of the Flight I/II was expanded in fiscal year (FY)1994 with the Flight IIA design. The Flight IIA design increased capability in multiple areas; most notably to incorporate helicopters (O'Rourke 2011). An overview of the resources allocated to the various ship classes from the Charles F. Adams class to the Arleigh-Burke Class Flight III are listed below in Table 15.

Table 15. Destroyer Resources by Surface Combatant

Category	**Charles F. Adams Class** (Susalla 1984)	**Arleigh-Burke Class** (SEA 00D 2021)		
		Flight I	**Flight IIA**	**Flight III**
Complement Total (officer/ enlisted)	354 (24 / 330)	329 (59 / 270)		
Missiles	Harpoon, Tarter, ASROC. (40-missile magazine)	Harpoon, Standard Missile, Vertical Launch anti-submarine rocket (ASROC), Tomahawk (96-cell magazine)	Harpoon, Standard Missile, Vertical Launch ASROC, Tomahawk, Evolved SeaSparrow Missile (ESSM), BMD, (96-cell magazine)	
Guns	2 five-inch 54 caliber	CIWS, 5-in. MK 45 Gun		
Anti-Submarine	2 triple torpedo tubes	2 triple torpedo tubes		
Radar	3D search, 2D air search, surface search, fire control	Integrated Aegis Weapons System with AN/SPY-1D		Integrated Aegis Weapons System with AN/SPY-6(V)1 Air and Missile Defense Radar
Countermeasures	Mk 36 super Rapid Bloom Offboard Countermeasures	MK 36 MOD 12 Decoy Launching System, MK 53 Nulka Decoy Launching System, AN/SLQ-39 chaff buoys		

Category	Charles F. Adams Class (Susalla 1984)	Arleigh-Burke Class (SEA 00D 2021)		
		Flight I	Flight IIA	Flight III
Sonar	SQS23 or SQQ23	SQQ89		
Aircraft	NA	NA	Two LAMPS MK III MH-60 B/R helicopters with Penguin/Hellfire missiles and MK 46/MK 50 torpedoes	

It is clear from Table 15 that over time the capability of each subsequent ship class has increased. The available missile types doubled between the Adams class and the Flight III ships, and the number of cells onboard more than doubled from 40 cells to 96 cells capable of supporting any mix of loadout. The countermeasure capability tripled between the Adams and Arleigh-Burke class. The Flight IIA and Flight III ships add two helicopters as resources aboard, further scaling up the resource allocation challenge.

As demonstrated with the destroyer, the resources allocated to a CSG have likely more than doubled in the past 50 years. In addition, the mission set has also increased for each unit of the CSG. The Flight III Arleigh-Burke class destroyer, for example, has an expanded mission set to now include aviation missions, BMD, and area defense for the other ships in the group. A decision-aid using AI for MMRA could undoubtedly assist the mission planners for both each individual unit as well as the overall CSG mission planner.

b) Complexity Analysis

The resource allocation challenge mission planners face also incorporates a time component that must be considered. For the ships in the group, and especially the aircraft carrier itself, turning or stopping takes considerable time and distance. The initial mission planning for the CSG would include the overall CSG mission as well as each unit's individual missions and resources.

For this capstone, the overarching CSG mission set of the U.S. Second Fleet was selected: to "command and control mission-ready forces to deter and defeat potential adversaries. Defend maritime avenues of approach between North America and Europe.

Strengthen our ability to operate with allies and partners in competition and conflict." (United States Navy n.d.) This mission, the mission sets for each unit in Table 12 as described in the Commander's intent, and all inputs discussed in Table 14 (CSG Resource allocation) would be passed to the MMRA AI. With this information, the MMRA AI would be exercised, and the initial resource allocation based on priority would be passed back to each unit.

The ships move out on their individual missions, and the MMRA AI CSG scenario begins at t_0. An example decision point: if a previously unknown red force unit (red force 1) attacked the CSG with several anti-ship cruise missile (ASCM). CG1 could expend two STANDARD missiles, three ESSMs, and several hundred rounds of CIWS before she suffers a casualty and must reprioritize her individual mission to ER damage control. By this time the CG2, SSN, DDG1, and DDG2 are each geographically dispersed. DDG1 is closer to the CG1, but one of her helicopters is undergoing maintenance and out of operation. CG2 can return from her individual mission but will take several hours to reposition. DDG2 has both helicopters operational, but the fuel she has onboard would require the T-AO to provide a RESUP mission to DDG2. The SSN is executing a SV mission, but based off the location of the ASCM could be in the general area of the adversary force who launched the ASCM. The commanding officer also has limited intelligence on if there are any additional red forces in the area. This one event leads to many different available COAs for the CSG commanding officer to deal with. Clearly, the CG1 needs help. Which resources to reallocate, and how to factor in new information such as the presence of previously undetected enemy forces can clearly overwhelm a decision maker. This incident would trigger decision point t_1 where the MMRA AI would need to be engaged to recalculate COAs for the mission commander. In this instance, the available resources and overall mission priority would have both likely changed.

With the AI-assisted MMRA tool, the CSG commander can quickly decide to reallocate resources. Some of the CVN resources and the T-AO are immediately reallocated to ER. Despite only having one helicopter, the DDG1 is ordered to also return for ER since the AI determined some of the CVN air assets can return quickly and assist with ER. The CG2 is ordered to strategically locate to defend the units attending to the

CG1. The DDG2 and SSN are reprioritized to establish where red force 1 is located and determine if any additional threats exist.

As the CG1 struggles to contain the casualty, the DDG2, SSN, and deployed aircraft from the CVN report additional contacts that potentially could be red forces. This information triggers decision point t_2. The data from all available sensors are passed back to the AI-assisted MMRA tool. With the help of the tool, COAs and the associated statistics are again presented to the decision maker for resource allocation. The CSG commander can determine to strategically maneuver the DDG1 to an optimal location to help CG2 provide area defense for the wounded CG1, CVN, and T-AO. Additionally, the AI MMRA tool indicated that the available weapons on the DDG2 and SSN are more than sufficient to neutralize the threat. Armed with the output from the tool, the CSG commander can efficiently assign resources.

Sometime later, CG1 could overcome the ER damage control scenario and be available to again support the greater CSG mission. This would trigger time t_3 when the mission planners would engage the MMRA AI to get the set of COAs based on new available resources. With CG1 damaged, weapons and sensors may need to be supplemented by aircraft from the CVN where possible. The MMRA tool could help mission planners determine which resources to allocate for this purpose. Table 16 lists the decision points for the CSG scenario.

Table 16. CSG Complexity Analysis Decision Points

Decision Point	CSG Scenario Event Resource Allocation
t_0	Initial missions established and executed. CVN (ACS), CG1 (AAW, ASW, ASUW, BMD), CG2 (AAW, ASW, ASUW), DDG1 (AAW, ASW, ASUW), DDG2 (AAW, ASW, ASUW), SSN (SV), T-AO (RESUP)
t_1	CG suffers casualty and must abandon her mission for ER. CVN (ACS, ER, INTL, RCN, SV), CG1 (ER), CG2 (AAW, ASW, ASUW), DDG1 (ER), DDG2 (AAW, ASW, ASUW, STK), SSN (INTL, RCN), T-AO (ER)
t_2	CVN aircraft, DDG2, and SSN report contacts that could be additional enemy forces. CVN (ACS, AAW, ASW, ASUW, ER), CG1 (ER), CG2 (AAW, ASW, ASUW), DDG1 (AAW, ASW, ASUW, ER), DDG2 (AAW, ASW, ASUW, STK), SSN (INTL, RCN, STK), T-AO (ER)
t_3	CG1 overcomes ER and can return to the overall CSG mission in a diminished capacity. CVN (ACS, AAW, ASW, ASUW), CG1 (AAW, ASW, ASUW), CG2 (AAW, ASW, ASUW), DDG1 (AAW, ASW, ASUW), DDG2 (AAW, ASW, ASUW, STK), SSN (INTL, RCN, STK), T-AO (RESUP)

Mission planners could engage the MMRA AI at any time to determine if reallocation of resources is warranted. However, caution is warranted to ensure missions are executed prior to reallocation unless superseding external factors warrant abandonment of a particular mission. An enemy attack during RESUP could be one scenario in which the RESUP mission must be terminated before completion. Similarly, ER is an emergent requirement that most often pulls resources from other mission allocations. Again, one can see the complexity inherent in maritime wartime operations.

V. ANALYSIS OF APPLICATIONS

For the next phase of the SE process, team AI Trio compared the use cases. Similarities and differences were examined to understand how an AI-assisted MMRA tool could be implemented. Features that work for one, two, or all three scenarios were identified to inform attributes, current capabilities, and requirements for the system. Additional considerations not explored in this capstone but necessary for successful implementation of the MMRA system are also highlighted in this chapter.

A. USE CASE COMPARISON PROCESS

Team AI Trio created a Venn diagram to best examine the three scenarios. Commonalities and divergences between the use cases are important to inform system management decisions for sponsors. The Venn diagram was also created to help inform the development approach to the system. The similarities and differences show which aspects of the system can be developed for universal application across all systems, and which aspects must be tailored for individual deployment within DOD applications. Figure 25 depicts similarities and differences between the three use cases studied. Section B and section C of this chapter highlight those similarities and differences.

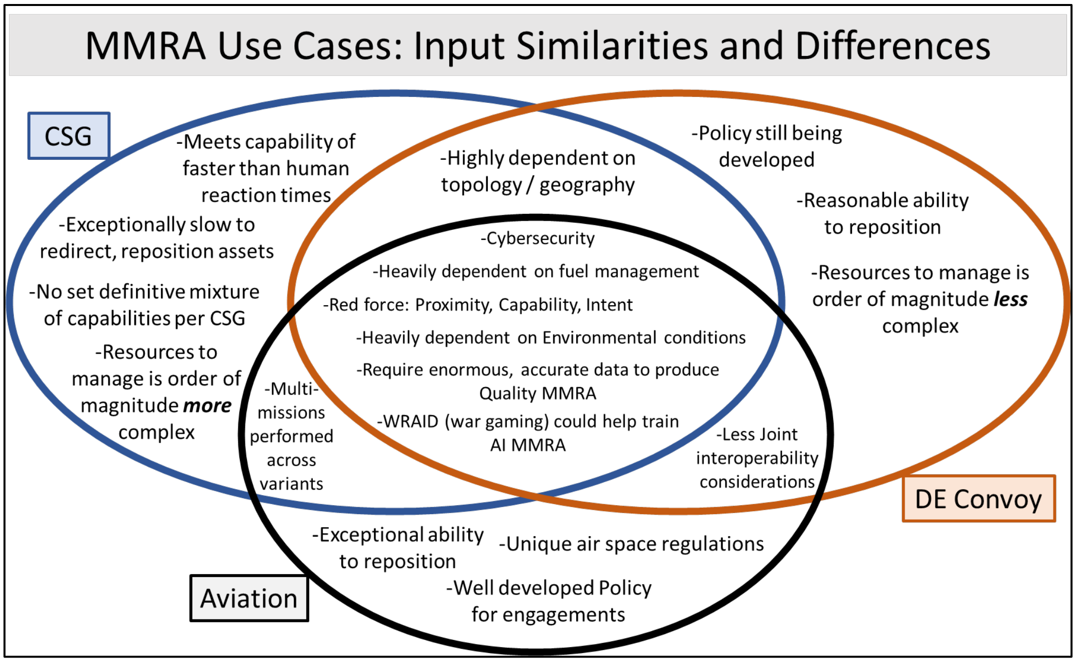

Figure 25. MMRA Use Cases: Input Similarities and Differences

B. SIMILARITIES

As shown at the center of Figure 25, each use case described in chapter III have several attributes in common. Table 17 lists the commonalities between the use cases. Identifying these overlaps is critical during system development and deployment. If cybersecurity considerations are required regardless of the application, then policies related to cyber can be designed into the core algorithms during development. Identifying these common requirements has the potential to streamline development and decrease the overall life cycle cost of the system.

Table 17. Use Case Attribute Similarities

Attribute	DE Convoy	Aviation	CSG
Cybersecurity	X	X	X
Heavily dependent on fuel management	X	X	X
Red force: proximity, capability, threat	X	X	X
Heavily dependent on environmental conditions	X	X	X
Require enormous, accurate data to produce Quality MMRA	X	X	X
WRAID (war gaming) could help train AI MMRA	X	X	X
Less Joint interoperability considerations	X	X	--
Multi-missions performed across variants	--	X	X
Highly dependent on topology / geography	X	--	X

All three use cases begin with finite resources that, within the operational scenarios, deplete over time. Fuel and munitions are expended as the resources execute their missions. While repairs may be made to certain assets to add them back into the available pool, the MMRA AI system will likely have the most available resources at the beginning of the scenario unless new resources are added from an outside source as seen in the DE convoy use case. The inputs to the MMRA AI system will likely change from the beginning of the operational scenario t_0 as new information becomes available, such as a change in intelligence, environmental conditions, or mission.

The time to reposition assets also applies to each of the three use cases. The MMRA AI must account for each resource and consider the time to reposition units into the COAs presented to mission planners. While one mission may have priority, the excessive time to reposition that ship or tank to the new location may disqualify it from consideration for that mission. With each COA, resources are prioritized for a given mission, and other missions may not have resource availability to execute effectively. Using AI to help MMRA will bring more calculated decision-making to the process.

Another commonality is that each use case is expected to include more assets and additional missions as the capabilities of systems expand. The three examples discussed how technological advancements have enabled each unit to expand the mission set and provide flexibility in the different functions they perform. This leads to interchangeability in missions and allows one unit to take over if another unit becomes disabled or needs to reprioritize their individual mission. However, the flexibility also creates a more complex decision-making environment for planners since more units can perform more missions.

C. DIFFERENCES

Differences between these use cases were also considered. Figure 25 depicts the divergent attributes of each of the scenarios around the edges of the Venn diagram. Those differentiating characteristics are listed in Table 18. Identifying areas where each application of the MMRA tool will require customizable software, additional hardware, or unique capabilities is imperative in the SE process. For instance, it may be easy to upload engagement doctrine for use by the AI in the MMRA tool for an aviation application, but the DE convoy may require extensive ML algorithms to help aid in the COA calculation. Each of the differentiating attributes can quickly render a common AI-enabled MMRA tool unusable unless careful design decisions are made in the development process to allow variation.

Table 18. Use Case Attribute Differences

Attribute	DE Convoy	Aviation	CSG
Policy still being developed	X	--	--
Reasonable ability to reposition	X	--	--
Resources to manage is order of magnitude *less* complex	X	--	--
Exceptional ability to reposition	--	X	--
Unique air space regulations	--	X	--
Well-developed policy for engagements	--	X	--
Meets capability of faster than human reaction times	--	--	X
Exceptionally slow to redirect, reposition assets	--	--	X
No set definitive mixture of capabilities per CSG	--	--	X
Resources to manage is order of magnitude *more* complex	--	--	X

Individual unit speed varies greatly between the scenarios: ships travel slowly, aircraft travel quickly, and the convoy land vehicles split the difference. Time considerations to pivot units to a new location will need to be tailored within the MMRA

AI toolset for each specific use case. Another difference between the scenarios is the complexity of the resources and their mission sets. Complexity varies on orders of magnitude: from the straightforward DE land convoy protection use case to the extremely complex CSG use case, with the aviation complexity falling between the other two. The scale of the CSG complexity may require multiple MMRA AI tools that feed into an overarching system. The DE land convoy protection may only require a single MMRA AI toolbox.

Operating policy governing the use cases also is contrasted between the examples considered. The CSG and aviation areas have established operating policies whereas the policy governing DE systems is still being developed. The lack of established operating policy for DE systems could impact the ability to produce a usable MMRA AI tool, or more likely expose the need for such a tool.

D. ADDITIONAL CONSIDERATIONS

A contingency of additional considerations were identified in this capstone study. The use cases explored the implementation of the MMRA tool as imagined in practice. However, all factors that affect the system require attention to design and deploy a successful product. These additional consideration areas could use subject matter expert consultation to realize an AI-enabled MMRA tool from concept to product development. Together with the use case analysis, these additional considerations inform design and deployment decisions for an AI-enabled MMRA system. With these factors considered, the resulting system will exhibit lower life cycle cost and higher metrics on performance and warfighter usefulness.

Within the SE community, a spider diagram is commonly used to map the connections among nodes in complex systems. For this study, the additional considerations were categorized via tactical evaluation process architecture: resources, missions, and constraints. Figure 26 depicts the asset spider diagram with the additional considerations for the MMRA AI black box system. As shown below, the largest area of categorized additional considerations are constraints such as human factors and cybersecurity.

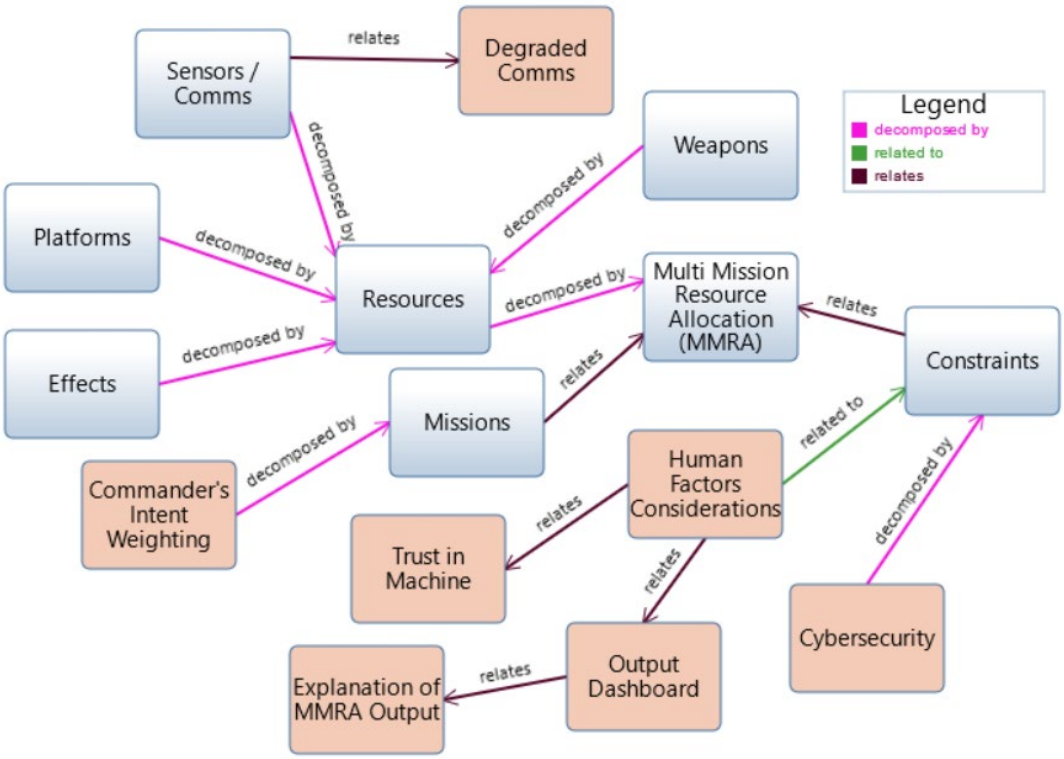

Figure 26. MMRA Spider Diagram: Additional Considerations

Backups and redundancy are critical in military systems. The MMRA AI, therefore must have protocol for when certain systems go offline, or an emergent situation forces the software to operate in a degraded state. A communication failure is an example in which the MMRA AI system may have to operate without the expected full set of input data. While degraded, the MMRA AI system should alert the end user of the limitation, but still provide a set of COAs. In this instance, the display of statistical confidence would indicate degraded performance.

The end user must be able to easily and expeditiously decipher the COAs. Human factors engineering can help in the design and usage of the MMRA AI system. Additionally, the system training and usage must elicit positive trust factors to encourage the user to execute based on the outputs. As the human is part of the system, without human factors engineering as a consideration the success of the system will degrade.

With competing priorities, no single COA can be expected to fully execute all missions effectively. Weighting of commander intent must be carefully considered when the calculation of the COAs is executed. For some use cases, there may only be one mission planner. For other more complex use cases such as the CSG example, each individual unit commander will have priorities. These priorities will need to be weighted appropriately with the CSG commander intent, and those mission planners at the strategic fleet forces level. The output COA's will need to take weighting into account and balance the resources. Some degradation to lesser missions likely will need to be accepted.

It would be beneficial to the user for the MMRA AI system to output what factors had the greatest influence on the different COAs. This information could help in the final decision-making of resource allocation. The known unknowns previously discussed are highlighted in orange. It should be noted that significant portions of known unknowns are HSI considerations that could be dedicated to a specialized team. Further, cybersecurity decomposition of MMRA constraints should include a certified subject matter expert for best results. With input from experts, the further decomposition of MMRA AI can be realized to best serve the future warfighter. Table 19 lists the additional considerations identified that will likely impact the MMRA system.

Table 19. Additional Considerations and Impact on MMRA System

Consideration	**Area of Influence**	**Relevancy to MMRA**
Resources	Sensors/Comms	Redundancy / degraded communication considerations
	Platforms	Modeling of platform performance. Variation of certain platforms and resources associated to them.
	Effects	Second / third order impacts of resource allocation changes
	Weapons	Modeling of weapon performance
Missions	Commander's Intent Weighting	Weighting algorithm development
Constraints	HSI trust in machine	Adoption of COAs. Trust in AI.
	Dashboard outputs / explanation	Clear displays with the right balance of data for quick decision-making
	Cybersecurity	Vulnerabilities

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VI. CONCLUSIONS

This chapter concludes the capstone report. The chapter contains a summary of the project explaining how the project objectives were met, recommendations for Navy consideration to adopt and implement a MMRA system, and a discussion of areas of future research related to MMRA.

A. PROJECT SUMMARY

The MMRA problem set is a challenge for modern mission planners. As technology advances, systems become more complex, and more systems are integrated into SoS, the inputs and considerations required will only increase. The research in this capstone report shows that AI has the potential to aid mission planners when allocating resources and complement the human decision maker. With finite resources, flexible platforms, and increasing mission sets, maximizing the efficiency of resource allocation is paramount to securing the interests of the U.S. Additionally, real-time changes in mission priorities and available resources often necessitate reallocation in extremely short timelines. There is a need for an AI-assisted MMRA system to ensure the mission is executed, particularly in future U.S. armed forces SoS.

The project objectives of this study guided the analysis of use cases and subsequent recommendations. To recap, the primary objective of this study was to explore how AI can aid mission planners and warfighters in effective MMRA for initial planning and dynamic replanning. The primary objective was thoroughly explored via the scalability and complexity analyzes of the three unique use cases. Each use case demonstrated that the MMRA problem set is expanding over time with an ability to augment an AI-enabled MMRA tool for human-machine teaming.

To compliment the main goal, four supporting objectives added to the robustness of the findings. The first supporting objective was to characterize complex military situations involving situations of multiple concurrent missions and limited resources. This was demonstrated through the common characterized decision points in the tactical evaluation process diagram and use case OV-1s. Each unique use case displayed an ability to integrate the AI-enabled MMRA process architecture into its multi-mission operational viewpoint. Similarly, the second supporting objective was to characterize the system context via inputs and outputs. This was demonstrated through the MMRA process architecture and MMRA process architecture action diagram. The third supporting objective to develop a high-level conceptual design of an AI-enabled MMRA capability added robustness to the first supporting objective. This third supporting objective was graphically summarized by the tactical evaluation process diagram which demonstrates the AI-enabled tool teaming with a human decision maker at distinct instances throughout the initial planning and dynamic replanning decision points. Lastly, the fourth supporting objective was to evaluate the similarities and differences of difference tactical scenarios. This objective was summarized in the MMRA use cases input similarities and differences Venn diagram. Each unique use case served as a diverse tactical MMRA perspective to compare MMRA inputs for an AI-enabled tool.

Across these three diverse use cases, this capstone used a SE approach to determine the feasibility of using AI to assist mission planners with MMRA. In each use case, the team researched inputs and external factors to explore design considerations for an MMRA AI black box that could assist decision makers in the different scenarios. Similarities and differences in the use cases were then analyzed to illuminate the MMRA problem set. Finally, additional considerations to the MMRA AI black box were proposed for future research.

B. RECOMMENDATIONS FOR ADOPTING THE MMRA SYSTEM

An MMRA AI tool will not be developed or implemented overnight. Many steps will be required to design, test, and implement a complete and robust AI-assisted MMRA toolset. The following sections propose a few recommendations for decision makers to help guide development.

1. Systems Engineering

It is recommended that the SE process be used to begin a small-scale program aimed to develop an MMRA AI tool for use at the tactical level. While the program will focus initially on the tactical level, stakeholders up to the strategic level should be included.

This will ensure the MMRA AI tool design can be scaled up to larger and more complex scenarios with minimal risk of needed redesign. Additionally, the employment of simulations will greatly improve the SE process for this effort. Not only will simulation data be beneficial for the development of the MMRA AI tool, but the data can also be used for the ML of the AI.

2. Data Collection for Machine Learning

Resource availability and readiness are already of great interest to all branches of the armed services. Mission planners can start with existing data on resource levels to determine where AI-assisted MMRA tools would be most beneficial. Efforts already underway to collect ship readiness levels can be expanded to include all available resources. An example for the Navy is the data collected by the NSWC Corona on ship and material readiness as part of the Readiness Assessment Department core functions (Naval Sea Systems Command n.d.). Warfare centers and strategic planners can assess the deltas between data already collected, and data sets required for input into MMRA algorithms.

3. Foster Buy-in

As Morison noted in his book *Men, Machines, and Modern Times*, people are reluctant to adopt new methods and technology. This is particularly true if it appears the new methods or technology are threatening careers, areas of responsibility, and resources (Morison 2016).

"Whenever a new device has been put into society—the loom, the internal-combustion engine, the electric generator—there have been temporary dislocations, confusions, and injustices. But over time men have learned to create new arrangements to fit the new conditions" (Morison 2016, 118).

It is imperative that stakeholders adopt and maintain support of an AI-assisted MMRA system to help facilitate development. This could be accomplished through case studies showing how AI is successfully used to help human beings with tasks ranging from day-to-day mundane tasks to complex and mentally taxing tasks. These cases studies could also show how the MMRA AI tool could give the military an edge over our adversaries.

Without this buy-in, a MMRA AI tool program will struggle through development or get canceled prior to demonstrating the benefits to the warfighter.

C. AREAS OF FUTURE RESEARCH

Future analysis of the AI-assisted MMRA problem set may be of interest to the U.S. Armed Forces. Due to the limited scope of this capstone, the team identified areas of research that have potential for added value.

1. Aspects of the Artificial Intelligence

The AI was treated as a black box for this study. Different aspects of how the AI will operate need to be researched further.

a) One MMRA AI tool versus multiple MMRA AI tools

Will optimizing the MMRA AI tool to specific use case inputs limit its usefulness in other use cases? If the ML is optimized for aviation, it may not translate well to another use case. It should be determined if there is a need or benefit to hierarchical layering of the MMRA AI tool. Separate tools for tactical, operational, and strategic levels should be researched to determine the proper balance.

b) MMRA hardware/software deployment strategy

If multiple MMRA AI tools are utilized, it will be necessary to determine how they should be deployed. A central command may provide a more stable environment, but also could hinder resource allocation if communication channels are compromised. These trade-offs will need to be explored to determine the proper deployment strategy.

c) Borrowing resources

With only a finite amount, the effects of borrowed resources between tactical levels, operational levels, and strategic levels should be explored. This may increase the complexity of resource allocation due to an increase in resource and mission considerations. Combined with weighting of commander's intent, borrowed resources could also severely degrade successful completion of subordinate mission sets.

d) Continuous vs. discrete

The feasibility of running the MMRA AI tool continuously should be researched. Not only will the MMRA AI tool need vast amounts of storage for the ML data, but it will also need a tremendous amount of computing power to process the input data and compute COAs. If running continuously requires more processing power than is currently available, the MMRA AI toolset may need to operate only in discrete runs.

e) MMRA replan thresholds for discrete mode

If MMRA tool is run in a discrete mode, a determination needs to be made as to what threshold dictates a replan decision point. Thresholds that need to be considered are:

1. Changes to individual unit availability (becomes available/unavailable)
2. Significant changes to intelligence on red forces (change in proximity, capability, or intent)
3. Red forces attack and deplete resources
4. Emergency operations (within the CSG, external to the CSG, natural disaster aid response)

2. Artificial Intelligence Machine Learning

There is an enormous amount of data available in areas such as historical, simulations, system testing, and resource capabilities across the branches of service that could be used for the AI ML. How can stakeholders be convinced to provide the necessary data? How is the data going to be collected and formatted such that it can be used for the ML? How is the AI going to be validated after it has gone through the ML process? If the MMRA AI tool is run continuously vs. discrete, how will the ML be conducted and fed into the system while it is running?

a) Artificial intelligence acceptance

As discussed in the recommendations section of this chapter, humans are naturally resistant to change. Breaking down trust barriers with AI is paramount to the successful deployment of an AI-assisted MMRA tool. How can this innate human tendency be overcome?

b) Data dashboarding

How can the inputs and outputs of the MMRA AI tool be displayed in a readable and understandable way? What information should be displayed? Should the information displayed be standardized or customizable? Which inputs have the largest impact on the resource allocation?

c) Clear and precise commander intent

Especially given the MMRA tool is intended to be just that, a tool, the commander intent must be clear and precise. Without clear precise intent, there is a risk of "garbage in, garbage out." It can be thought of like the spell check/grammar check in a word processing program. If the user of the word processing program is close to the intended word or phrase, the program can assist the user fine tune the spelling or grammar. If the user puts in just a mix of letters, the program is going to be of little use. Research should be conducted to see what makes for a clear and precise commander intent and how the AI could help develop this clear and precise commander intent.

d) Artificial intelligence ethics

The ethics of utilizing AI to make MMRA recommendations will need to be explored. The value weighting of human versus equipment resources allocated to areas of active conflict will need to be resolved. Even with a human in the loop making the final decision, these ethical issues could be difficult to overcome.

LIST OF REFERENCES

AFSOC Public Affairs. 2020. *CV-22 Osprey.* Fact Sheet, Air Force. "CV-22 Osprey." Air Force. AFSOC Public Affairs, August 2020.

Airforce Technology. 2000. "Airborne Laser System (ABL) YAL 1A." *Airforce Technology.* November 7. Accessed December 7, 2021. https://www.airforce-technology.com/projects/abl/.

Axe, David. 2022. "One Shot, One Kill: Ukrainian Gunners Fire Laser-Guided Shells At Russian Vehicles." *Forbes.* April 5. Accessed May 26, 2022. https://www.forbes.com/sites/davidaxe/2022/04/05/one-shot-one-kill-ukrainian-gunners-fire-laser-guided-shells-at-russian-vehicle.

Badalyan, Rachel, Andrew Graham, Michael Nixt, and Jor-El Sanchez. 2022. *Application of an Artificial Intelligence-Enabled Real-Time Wargaming System for Tactical Operations.* Capstone Report, Monterey: Naval Postgraduate School.

Beckman, Walt. n.d. *So You're the Convoy Commander. What Now?* Accessed August 1, 2022. https://safety.army.mil/MEDIA/Risk-Management-Magazine/ArtMID/7428/ArticleID/6896#:~:text=A%20tactical%20convoy%20is%20a,and%20cargo%20by%20ground%20transportation.

Bell. 2022. *Bell V-280 Valor.* Accessed December 2021. https://www.bellflight.com/products/bell-v-280.

Capaccio, Anthony. 2022. "Tank-Busting Switchblade Drone Closer to Joining Aid to Ukraine." *Bloomberg.* May 11. Accessed May 26, 2022. https://www.bloomberg.com/news/articles/2022-05-11/tank-busting-switchblade-drone-closer-to-joining-aid-to-ukraine?srnd=premium&sref=IYQ5m.

Deputy SECDEF. 2021. *Establishment of the Chief Digital and Artificial Intelligence Officer.* Washington, D.C., 12 08.

Deputy Secretary of Defense. 2012. *Mission Assurance Strategy April 2012.* Washington, D.C., 05 07.

Drummond, Mark, John Bresina, and Smadar Kedar. 1991. "The Entropy Reduction Engine: Integrating Planning, Scheduling, and Control." *The SIGART Newsletter, Volume 2, Number 4*, 08: 61–65.

Eversden, Andrew. 2021. “Strykers To Get New Counter-Drone Tech With General Dynamics, Epirus Partnership.” *Breaking Defense.* October 25. Accessed 2022. https://breakingdefense.com/2021/10/strykers-to-get-new-counter-drone-tech-with-general-dynamics-epirus-partnership/.

Gaynor, Michael. 2020. *Automation and AI sound similar, but may have vastly different impacts on the future of work.* January 29. Accessed July 25, 2022. https://www.brookings.edu/blog/the-avenue/2020/01/29/automation-and-artificial-intelligence-sound-similar-but-may-have-vastly-different-impacts-on-the-future-of-work/.

Geerges, Mimi, MG Walter T Rugen, and BG Robert Barrie. 2021. “Transforming Army aviation to prepare for threats through Future Vertical Lift.” *Government Matters, Sinclair Broadcast Group, ABC 7News.* September 22. Accessed 2021. https://govmatters.tv/.

Gill, Jaspreet. 2021. “Bell, Sikorsky Move to Second Phase of FLRAA CD&RR.” *Inside Defense.* March 30. Accessed 2022. https://insidedefense.com/insider/bell-sikorsky-move-second-phase-flraa-cdrr.

Goodman, James, Simon Lucas, and Sebastian Risi. 2020. *AI and Wargaming.* Dissertation, UK: Defence Science and Technology Laboratory (DSTL) UK Ministry of Defence.

IBM Cloud Education. 2020. *Neural Networks.* August 17. Accessed July 17, 2022. https://www.ibm.com/cloud/learn/neural-networks.

———. 2020. *Supervised Learning.* August 19. Accessed July 17, 2022. https://www.ibm.com/cloud/learn/supervised-learning.

Johnson, Bonnie. 2019. “Artificial Intelligence—an Enabler of Naval Tactical Decision Superiority.” *AI Magazine*, 03 28: 63–78.

———. 2021. “Artificial Intelligence Systems: Unique Challenges for Defense Applications.” *in Proceedings of the 18th Annual Acquisition Research Symposium.* Monterey, CA: Naval Postgraduate School. 321–332.

———. 2022. “Class discussion on tactical decision timeline.” Naval Postgraduate School Capstone Course, June 2022.

Joint Targeting School. 2017. *Joint Targeting School Student Guide.* Training Doctrine, Dam Neck, VA: U.S. Department of Defense (DOD).

Jones-Bonbrest, Nancy. 2020. *Scaling Up: Army Advances 300kW-class Laser Prototype.* March 3. Accessed July 10, 2022. https://www.army.mil/article/233346/scaling_up_army_advances_300kw_class_laser_prototype.

Leonardo DRS. n.d. *Maneuver Short-Range Air Defense (M-SHORAD).* Accessed August 1, 2022. https://www.leonardodrs.com/what-we-do/products-and-services/m-shorad/.

Lockheed Martin. 2022. *Future Vertical Lift: SB-1 Defiant.* Accessed December 2021. https://www.lockheedmartin.com/en-us/products/sb1-defiant-technology-demonstrator.html.

Military Aerospace Electronics. 2020. "Army orders new UH-60M and HH-60M Black Hawk helicopters for cargo, troop carrying, and medical evacuation." *Military Aerospace Electronics*, December 11.

Morison, Elting E. 2016. *Men, Machines, and Modern Times.* Massachusetts: Massachusetts Institute of Technology.

Naval Sea Systems Command. n.d. *Warfare Centers, NSWC Corona Division.* Accessed 07 17, 2022. https://www.navsea.navy.mil/Home/Warfare-Centers/NSWC-Corona/What-We-Do/Readiness-Assessment-Department/.

O'Rourke, Ronald. 2011. *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress.* CRS Report for Congress, Washington, D.C.: The Library of Congress. https://sgp.fas.org/crs/weapons/RL32109.pdf.

PEO Aviation. 2020. "Utility Helicopter UH-60M." *U.S. Army.* September 25. Accessed December 2021. https://www.army.mil/article/239415/utility_helicopter_uh_60m.

Pfau, Nathan. 2018. "AH-56 Cheyenne: Still an aircraft way ahead of its time." *Fort Rucker, U.S. Army.* Accessed December 2021. https://www.army.mil/article/206181/ah_56_cheyenne_still_an_aircraft_way_ahea d_of_its_time.

SEA 00D. 2021. *Destroyers (DDG 51).* 09 29. Accessed 06 04, 2022. https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2169871/destroyers-ddg-51/.

Shwartz, Joe. 2003. "Tactical High Energy Laser." *Journal of Directed Energy* 35–47.

Sof, Eric. 2017. "Kamov Ka-52 Alligator: A next-Generation Combat Helicopter." *Spec Ops Magazine.* May 29. Accessed December 2021. https://special-ops.org/kamov-ka-.

Susalla, Paul K. 1984. *An Application of AMORE (Analysis of Military Organizational Effectiveness) to the Charles F. Adams class Guided Missile Destroyer.* Thesis, Monterey: Naval Postgraduate School.

Swanson, Keith, Mark Drummond, and John Bresina. 1992. *An Application of Artificial Intelligence to Automatic Telescopes.* NASA-TM-108115, Mountain View: NASA AMES Research Center.

Tesla. n.d. “Tesla Dojo Technology.” Accessed July 17, 2022. https://tesla-cdn.thron.com/static/SBY4B9_tesla-dojo-technology_OPNZ0M.pdf?xseo=&response-content-disposition=inline%3Bfilename%3D%22tesla-dojo-technology.pdf%22.

Thompson, David L. 2012. “Convoy Security Shortfalls.” Master’s thesis, United States Army Command and General Staff College. https://apps.dtic.mil/sti/pdfs/ADA569938.pdf.

United States Army Acquisition Support Center. n.d. *Counter-rocket, artillery, mortar (C-RAM) intercept land-base phalanx weapons system (LPWS).* Accessed August 1, 2022. https://asc.army.mil/web/portfolio-item/ms-c-ram_lpws/.

United States Army CCDC Army Research Laboratory Public Affairs. 2019. *Army game-theory research better allocates military resources, fight cancer.* July 15. Accessed July 25, 2022. https://www.army.mil/article/224441/army_game_theory_research_better_allocates_military_resources_fight_cancer.

United States Marine Corps. n.d. “The Official website of the United States Marine Corps.” *Motorized Convoy Operations B4P4878 Student Handout.* Accessed August 1, 2022. https://www.trngcmd.marines.mil/Portals/207/Docs/TBS/B4P4878%20Motorized%20Convoy%20Ops.pdf.

United States Navy. 2021. *Aircraft Carriers - CVN.* 11 12. Accessed 05 06, 2022. https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2169795/aircraft-carriers-cvn/#:~:text=Aircraft%20carriers%20support%20and%20operate,of%20U.S.%20and%20coalition%20forces.

———. n.d. *CSG-4 Mission.* Accessed 07 31, 2022. https://www.csg4.usff.navy.mil/About-Us/Mission/.

———. n.d. *Mission, Commander U.S. Second Fleet.* Accessed 07 31, 2022. https://www.c2f.usff.navy.mil/About-Us/Mission/.

———. 2019. *PEO Aircraft Carriers Public Affairs.* 06 21. Accessed 07 21, 2022. https://www.navsea.navy.mil/Media/News/SavedNewsModule/Article/1883486/downey-takes-command-of-program-executive-office-aircraft-carriers/.

———. n.d. *USS Carl Vinson (CVN 70).* Accessed 07 31, 2022. https://www.airpac.navy.mil/Organization/USS-Carl-Vinson-CVN-70/About-Us/.

Weapons Detective. 2020. “FLRAA Programme | the V-280 Valor versus the SB-1 Defiant.” *Youtube Video Blog.* September 29. Accessed 2022. https://www.youtube.com/watch?v=_kp4xB8za5Q.

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