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Ellis Class MMRC Surface Squadrons in Competition and Conflict

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ELLIS CLASS MMRC SURFACE SQUADRONS IN COMPETITION AND CONFLICT

by

Eugene P. Paulo

December 2023

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ABSTRACT

The research assesses the makeup and capabilities of Multi-Mission Reconnaissance Craft (MMRC) squadrons in view of how effectively they could accomplish a given mission. This effort consisted of the development of an MMRC squadron system architecture, which defines and describes the functional and operational use of the MMRC squadron within the littoral operations area (LOA). Various measures of effectiveness (MOE) were explored and analyzed to determine which metrics were most relevant to evaluate the successful employment of the MMRC squadrons. This was done to determine what functional and operational parameters carry the most weight when considering the capabilities of the MMRCs as well as the MMRC squadrons. Simulations were developed in Map Aware Non-Uniform Automata (MANA) for a subset of missions in both a competition scenario and a conflict scenario. A design of experiments was developed for each scenario and simulation analysis determined which input factors had the most significant impact on operational success. While significant factors varied per each MOE, radar classification range and aperture arc overall played a significant role suggesting that MMRC design should focus on procuring the best possible radar. For conflict, radar factors also played a significant role, alongside the number of hits it took to 'kill' the MMRC. This suggests that focusing on durable design is an important part of ensuring success on missions in active conflict.

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I. INTRODUCTION

A. BACKGROUND

The United States Marine Corps (USMC) is considering the role it may have to play in support of multi-domain reconnaissance and counter reconnaissance force operations. Such a role differs inherently from the large-scale amphibious forcible entry, and this new force design calls for the capabilities of littoral maneuver and persistent operability within range of adversary long-range fires. The concept of expeditionary advanced base operations (EABO) contains the additional requirement of the design and deployment of smaller, distributable, lower signature, and more affordable amphibious ships that will be able to operate as stand-in forces (SIF) in the surrounding EABO network.

One intent for SIF is the need for small craft to support Marine Reconnaissance and Counter Reconnaissance (M-RXR) operations in the littorals. A proposed solution to this requirement is a Multi-mission Reconnaissance Craft (MMRC) that would operate in squadrons from an EABO. This research project illustrates the deployment of these MMRC squadrons in a potential scenario. This scenario is used to aid in the development and analysis of functional and operational parameters of the MMRC squadrons and the design factors to be considered in their concept of employment.

This document is essentially a condensed version of the final report generated through a research effort conducted by a team of NPS systems engineering graduate students, Humphries et al. (2023).

1. EABO

The Chief of Naval Operations and the Commandant of the USMC established the EABO, which became a foundational naval concept in 2019 to counter adversaries operating in forward littorals (Marine Corps 2021b). The EABO aims to enhance U.S. and partner nation capabilities in critical maritime areas by integrating the Fleet Marine Force (FMF) and Navy forces to facilitate sea denial, sea control, and to provide sustained support to the fleet (Marine Corps 2021b). The EABO tasks include conducting surveillance and reconnaissance, conducting surface warfare, sustainment, strike, forward arming and refueling points, and operations in the information environment. An expeditionary advanced base is stationed within an adversary's weapon engagement zone (WEZ) to conduct these operations while defending friendly forces in the area. These bases are not meant to be permanent as they must change locations often to remain having an advantage over adversaries (Marine Corps. 2021b).

2. SIF

SIF are small but lethal units created to conduct operations and missions that are designed to either gather intelligence or disrupt the plans of a potential or actual adversary (Marine Corps. 2021a). These forces typically operate near an adversary, which requires on-station persistence, agility, and timeliness of reporting (Marine Corps. 2021a). It is crucial that these operations are done in a timely manner to thwart potential adversaries. SIF are intended to shape the forward operational environment gathering intelligence, conducting surveillance, and contributing to the denial of emerging threats (Marine Corps 2021a).

3. MMRC

While the Ellis-Class MMRC does not yet exist, several existing craft have capabilities that meet many of the identified requirements. The Mark VI Patrol Boat is perhaps the closest existing vessel to the proposed Ellis MMRC. The design characteristics of both hulls will be very similar in terms of length, beam, and draft (United States Navy 2018), which are well suited to perform the intended SIF missions in littoral areas. Nevertheless, the MMRC will be lighter in weight and faster than the Mark VI Patrol Boat to provide enhanced maneuverability and capabilities (U.S. Navy 2018).

B. PURPOSE OF RESEARCH

This research assesses the makeup and capabilities of the MMRC squadrons in view of how effectively they could accomplish the given mission. This effort consisted of the development of an MMRC squadron system architecture which defines and describes the functional and operational use of the MMRC squadron within the littoral operations area (LOA). Within the defined architecture, various measures of effectiveness (MOE) were explored and analyzed to determine which metrics were most relevant to evaluate the successful employment of the MMRC squadrons. Lastly, this research determines what functional and operational parameters are most significant when considering the capabilities of the MMRCs as well as the MMRC squadrons. This research addresses three specific questions:

- How well do the proposed composition and capabilities of Ellis-Class MMRC squadrons prevent, deter, disrupt, or reduce adversary incursions into partner nation littoral territory?
- What (MOEs best represent the achievement of success in the employment of Ellis-Class MMRCs in an operational scenario?
- What are the significant design decisions and operational parameters for the Ellis-Class MMRCs that provide the largest impact on the MOEs in relevant and complex operational scenarios?

C. OPERATIONAL SCENARIOS

The overall mission outlined in the scenario is to employ SIF comprised of MMRC squadrons for operational use within the adversary's WEZ. This study executed two scenarios, one during the competition phase and the other during the conflict phase. The U.S. objective in both the competition and the conflict scenarios was to use these MMRC squadrons to identify, track, deter and deny adversary incursions into a partner nation's littoral territory and international waters.

"Hard to Find, Impossible to Ignore" (Lusczynski 2022) defined two distinct roles for the current employment of MMRC squadrons. In a competition below the armed conflict environment, the focus is on longer-term efforts to exert pressure on adversaries, preventing them from achieving their operational objectives without escalating the situation. If the situation does escalate into an armed conflict environment, the focus then shifts to more open and active methods of defeating and denying enemy objectives (Joint Chiefs of Staff 2019). For each scenario, an OV-1 diagram was created to illustrate the operational environment being described.

1. Scenario A: Competition below Armed Conflict

U.S. Marines have established an EABO in coordination with the Philippine Navy and Marine Forces on Palawan Island. The U.S. Navy deploys a task group under the SEVENTHFLT Commander. MMRC Groups, composed of 4x MMRC squadrons, are deployed to support USMC SIF. Each squadron is responsible for specific areas of interest. MMRC squadrons deploy from the expeditionary advanced base (EAB), consisting of 1x Seaplane, 1x MMRC Tender, and 6x MMRCs. MMRC squadrons are equipped with an assortment of unmanned reconnaissance vehicles. MMRCs are configured for reconnaissance and self-defense with the ability to reconfigure at the EAB. Alongside Philippine forces, they conduct persistent zone reconnaissance in the assigned area of the LOA. Combined maritime patrols are conducted to support Philippine maritime territorial integrity activities within the Philippine territorial waters and to provide ISR for U.S. and Philippine forces. The SIF also provide support to higher headquarters including Electromagnetic Spectrum monitoring, recording baseline surface ship patterns, recording baseline subsurface activities, and identifying sites for future EABs. These tasks meet the Commander's Intent of maintaining freedom of navigation, territorial integrity, and protecting sea lines of communication (SLOC) while also maintaining awareness of Chinese navy movements and pattern of life. Figure 1 shows an OV-1 diagram highlighting the operations undertaken in this scenario.

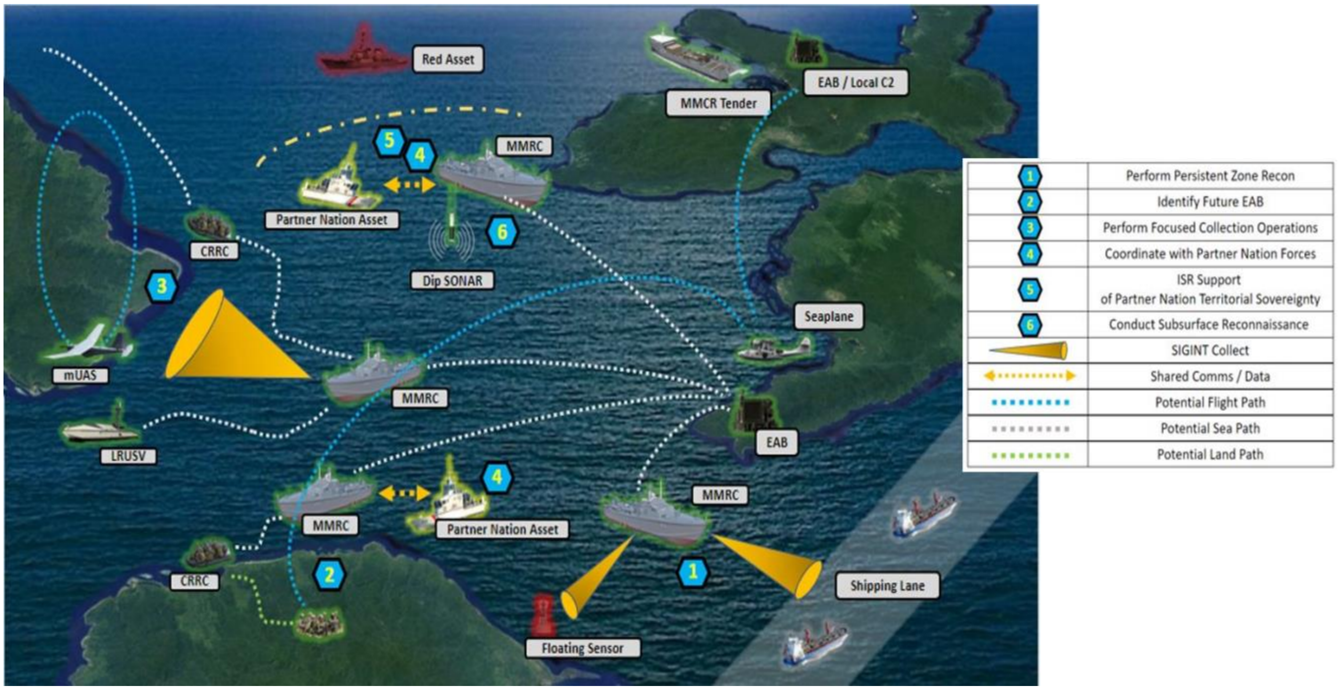

Figure 1. OV-1 for MMRC Squadron Operations in a Competition Scenario

2. Scenario B: Armed Conflict

The Chinese navy has interdicted and sunk a Philippine navy ship conducting a security patrol off Palawan. The MMRC squadrons continue to conduct combined maritime patrols with the Philippine navy. These patrols move into position to identify and disrupt malign PRC activities, support joint fires of surface targets, and support anti-submarine warfare (ASW) with unmanned underwater vehicles (UUVs). The SIF enable Joint Forcible Entry Operations, including maritime convoy scouting and screening, insertion of EAB teams, support to contested amphibious landings, tactical recovery of aircraft and personnel (TRAP), and to provide intelligence, surveillance, and reconnaissance (ISR) and targeting support for elements of a U.S. Navy Carrier Strike Group (COMCARSTRKGRU) that has been positioned in international waters to provide air defense and a strike capability if required. These tasks meet the Commander's intent of controlling sea lanes of communication, enabling naval maneuvering, marine littoral operations, and joint access throughout LOA Cyclone. Figure 2 shows an OV-1 diagram highlighting the operations undertaken in this scenario.

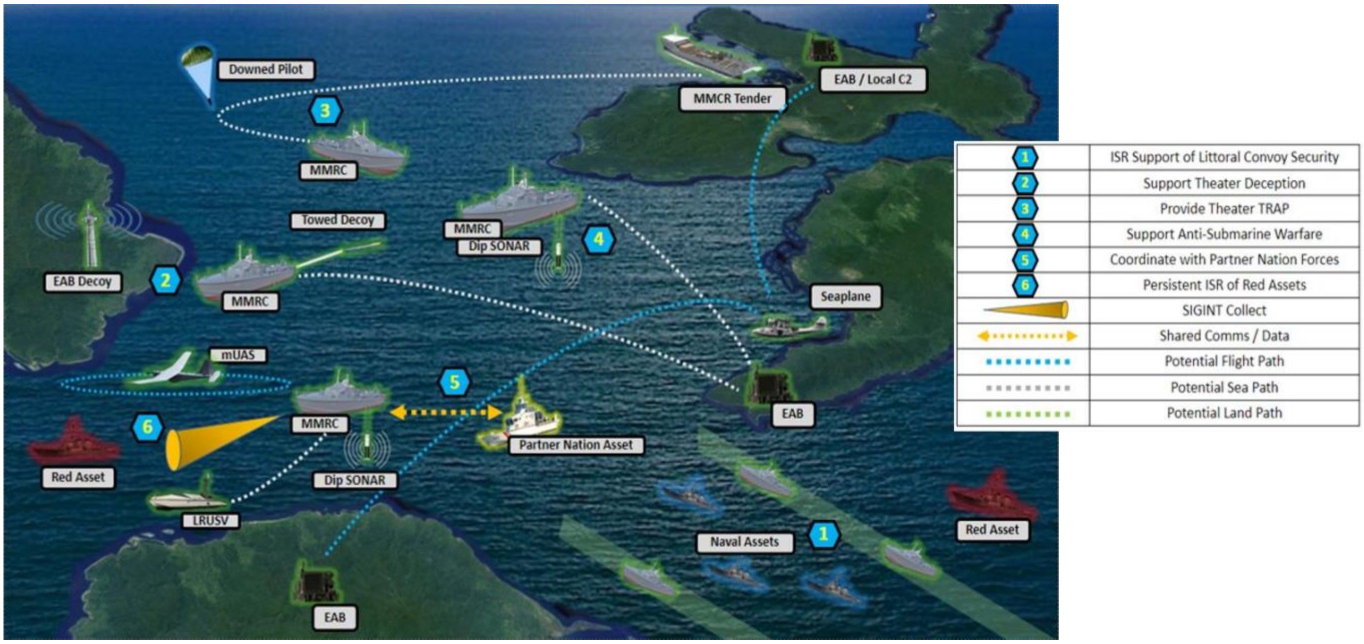

Figure 2. OV-1 for MMRC Squadron Operations in a Conflict Scenario

D. SYSTEMS ENGINEERING PROCESS

The application of a model-based systems engineering (MBSE) framework was integrated with mission engineering analysis to thoroughly address operations of the MMRC squadrons. Utilizing the principles for integrating MBSE into mission engineering efforts as discussed in Beery and Paulo (2019), a tailored Vee process model was developed to guide this project as shown in Figure 3. This model isolates the decomposition-focused left half of the legacy systems engineering Vee and adds additional MBSE focused steps to ensure the modeling and simulation of the mission system is captured. The operational and system modeling phases focus on the creation of the architectural models, while the system analysis phase involves the development of operational simulations and the analysis of simulation results.

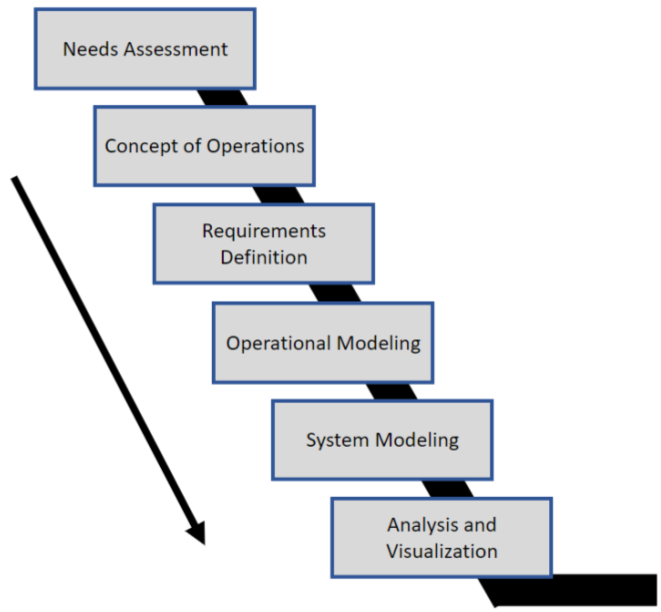

Figure 3. Systems Engineering Process

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II. SYSTEM MODELING

A. PHYSICAL SYSTEM COMPOSITION

Since many of the individual components of the MMRC squadron are still in high-level concept stages, the physical composition was focused at the overall system level to better understand how the different components interacted with each other. The top level of the physical composition of the MMRC Squadron is shown in Figure 4.

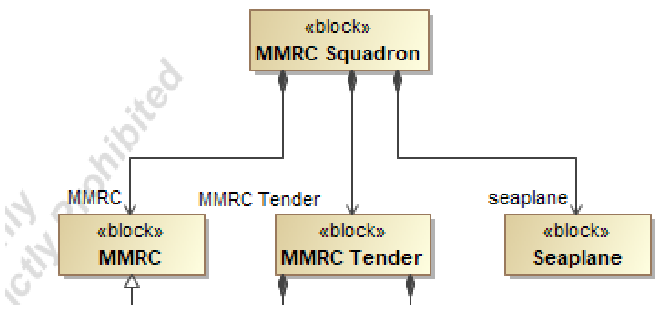

Figure 4. Top Level Physical Composition of MMRC Squadron

The MMRC squadron is composed of the MMRCs, one MMRC Tender, and one sea plane. There will be six MMRCs in the MMRC squadron. Each MMRC will carry at least one unmanned aerial vehicle (UAV) and a combat rubber reconnaissance craft (CRRC). The MMRCs will have the capability to deploy and recover both the UAV and the CRRC. The MMRC will launch the CRRC via an aft ramp. In a competition scenario, the CRRC will be utilized to assist in key functionalities such as persistent zone reconnaissance and identifying and reporting potential future EAB sites. The MMRC Tender will carry at least one UUV and unmanned surface vehicle (USV), specifically a long-range USV (LRUSV). Like the UAV and CRRC, the UUV and LRUSV will also be prepared and deployed to assist in key functionalities of persistent zone reconnaissance.

B. PRIMARY SYSTEM FUNCTIONS

The primary source of needs and functionality of the MMCR squadron system are from Lusczynski (2022). This document includes a wide range of employment concepts under both competition and conflict environments, with detailed vignettes showing potential operational applications of the concepts. After reviewing these concepts and speaking directly with the stakeholder, the following four major capabilities are desired through the employment of MMRC squadrons:

Persistent Operations: The capability to maintain an open and persistent presence within the LOA to support reconnaissance and zone access.

Intelligence, Surveillance and Reconnaissance (ISR): The capability to collect information on the current condition of the LOA and monitor the movement of the adversary.

Theater Operation Support: The capability to conduct missions within the theater of operations that provide support to the fleet through TRAP and deception.

Communication: The capability to provide information and intel from the LOA to the fleet through the transmission of data to the EABO.

Identifying the primary capabilities was critical for focusing the scope of this effort and guided the development of the requirements and system functions. All requirements and functions developed throughout the capstone fall under one or more of these four major capability areas. Figure 4 shows the capability matrix mapping developed to show how the top-level system functions for the MMRC squadron tie into each of the capabilities. Each function is described in more detail in the following section.

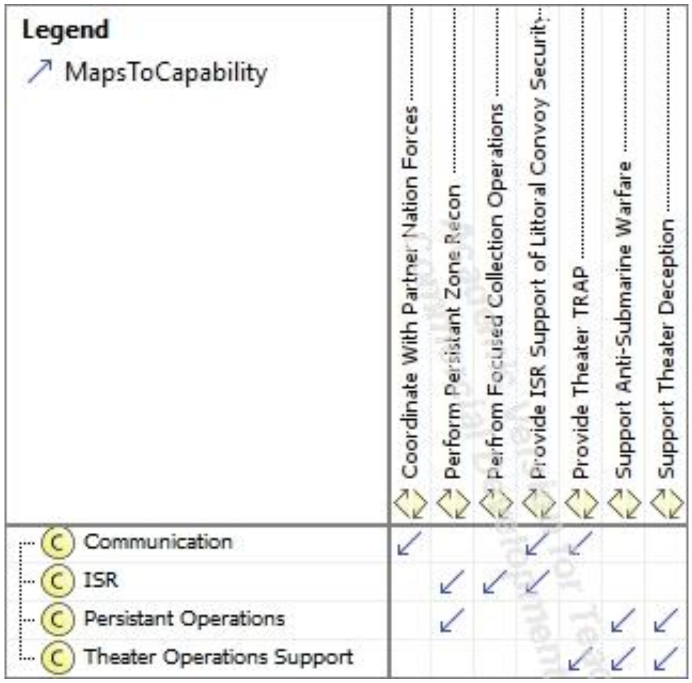

Figure 5. Capability Matrix Mapping

C. FUNCTIONAL ANALYSIS

A functional analysis was conducted that yielded the functional hierarchy of operational activities depicted in Figure 5. The purpose of this hierarchy is twofold: first, to further develop the operational uses of the MMRC squadron as described in the operational scenarios; and second, to show the relationships between the system requirements and the parameters of the concept of operations.

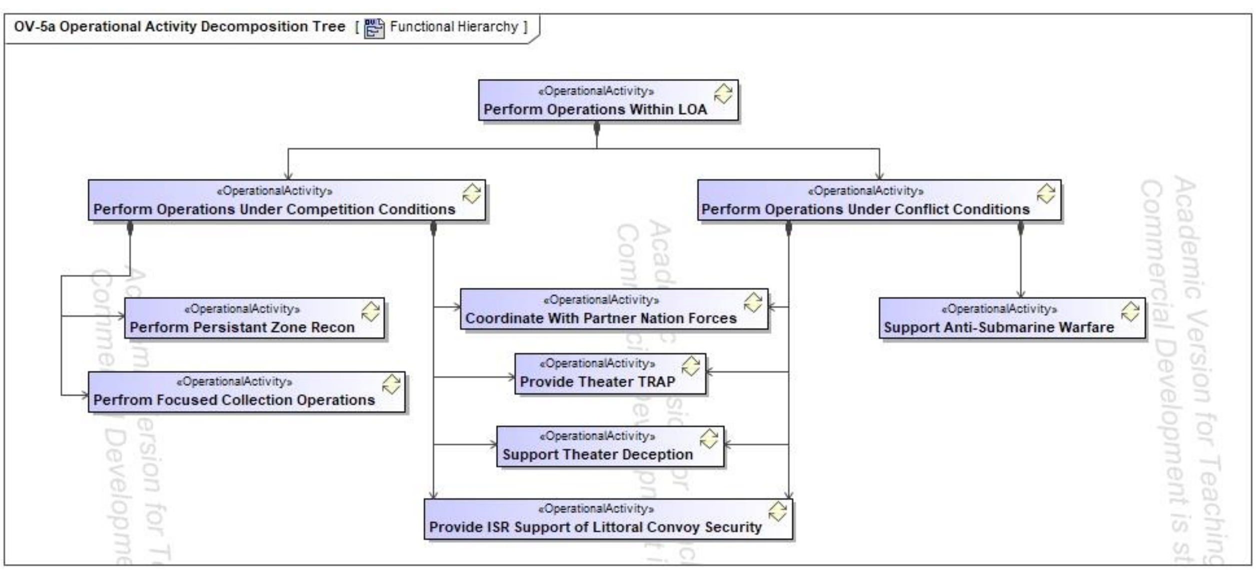

Figure 6. Functional Hierarchy

The top-level function "Perform Operations Within LOA" defines the base context that governs all MMRC squadron operations. Subsequently, the second-level functions provide the delineation between operations that the MMRC squadron will be performing while under varying stages of war. These operations align with the two separate detailed scenarios that were identified while refining the problem definition for the capstone. The third-level functions relay the operations that one or more MMRCs may perform under either condition, including functions that reflect operations under both conditions. Each of these seven third-level functions are broken down further and serve as the basis for the development of MOEs and measures of performance (MOPs).

Perform Persistent Zone Recon: Activities needed to maintain a persistent presence in the LOA and collect and communicate information about the environment and adversaries' movements.

Perform Focused Collection Operations: Activities performed by an MMRC for the purposes of gathering information on a pre-determined target.

Coordinate With Partner Nations: Activities depicting the MMRC's role in facilitating communication networks between the U.S. forces and those of the partner nations.

Provide Theater TRAP: Activities outlining the role of the MMRC in searching, locating, and recovering stranded personnel.

Support Theater Deception: Activities allowing the MMRC to spoof larger forces and create distractions that mislead the adversary from their original mission.

Support Anti-Submarine Warfare: Activities allowing the MMRCs to monitor and deter sub-surface threats.

Provide ISR Support of Littoral Convoy Security: Activities depicting the MMRCs providing extended ISR capabilities to a littoral convoy security force for purposes of early warning.

D. PERFORMANCE METRICS

1. Competition Measures of Effectiveness

Table 1 shows the MOEs chosen for the competition scenario, along with the functions that relate to each measure. As mentioned in the operational scenario for competition, the MMRC squadron's mission is to support the Philippines in their efforts to send supplies to the BRP SIERRA MADRE grounded on Second Thomas Shoal (2TS). The MMRCs will provide scouting around the area of 2TS, providing information and employing deception to prevent the adversarial ships from interfering with the Philippines shipping vessels by driving them away from 2TS. The effectiveness of these tactics can be measured in the number of times the shipping vessels are successfully able to deliver their supplies without being blocked by the adversaries, how many adversarial identifications the MMRCs are able to make to inform others of adversarial presence, and the percentage of time that the MMRCs spend in direct pursuit of the adversarial ships to deploy their deception tactics.

Table 1. Measures of Effectiveness for the Competition Scenario

Measure of Effectiveness	Function
Number of Successful Resupply Missions	Perform Persistent Zone Recon, Support Theater Deception & Provide ISR Support of Littoral Convoy Security
Number of Adversary Detections	Perform Persistent Zone Recon
Time Spent Pursuing Adversaries (%)	Support Theater Deception

2. Conflict Measures of Effectiveness

Table 2 shows the MOEs chosen for the conflict scenario, along with the functions that relate to each measure. In the conflict scenario, the MMRCs mission is to provide ISR in support of a COMCARSTRKGRU traversing through an active combat zone, and to provide TRAP support to any injured allies. For this, mission success is measured in the number of adversarial identifications the MMRCs make to inform allies of incoming adversaries, the percent of downed allies the MMRCs are able to rescue, and the number of MMRCs that are able to survive through a mission with active combat.

Table 2. Measures of Effectiveness for the Conflict Scenario

Measure of Effectiveness	Function
Number of Adversary Detections	Provide ISR Support of Littoral Convoy Security
% of Downed Allies Rescued	Provide Theater TRAP
Survivability of MMRCs	Provide ISR Support of Littoral Convoy Security & Provide Theater TRAP

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III. OPERATIONAL MODELING

A. SIMULATION OVERVIEW

An agent-based model developed by the New Zealand Defense Technology Agency called Map Aware Non-Uniform Automata (MANA) was chosen as the operational simulation environment. The use of MANA is intended to allow for the discovery of interactions between different agent groups and to thereby discover potential emergent behaviors that can develop from these relationships (Anderson 2013). Given that the MMRC squadron's mission focuses on conducting ISR and responding to changes in the environment around it, utilizing an agent-based simulation tool to model their behaviors seemed most appropriate.

B. TWO SCENARIOS MODELED

The simulation map covers a 200 nm x 200 nm area off the western shore of Palawan, Philippines. The MMRC squadron base of operations are in the areas surrounding the waters of Palawan and 2TS, with the adversarial base centered in the upper left by Tizard Bank and Union Banks. The terrain is kept simple with all landmasses marked as impassable by ships, and open water marked as traversable areas. Those areas with generally rougher sea states are represented by differing shades of blue, with the darker shades of blue being more difficult to traverse than the lighter shades.

1. Competition Simulation

This simulation was developed based on the competition operational scenario described in the first chapter, in which the MMRC squadron is deployed to provide scouting and defense for Philippines shipping vessels attempting to conduct a series of resupply trips to 2TS over the course of 96 hours. In actual operation, there would not be multiple resupply missions in a four-day time span; however, since MANA measures simulation time steps in seconds, it would take too much time and computing power to simulate a mission over a longer period of several months. Two pairs of MMRCs are stationed around the area of 2TS providing persistent zone reconnaissance, with one group providing forward scouting into Chinese waters and the other patrolling to the east. The third pair of MMRCs are stationed alongside a pair of Philippines shipping vessels, providing protection for the vessels as they travel from Palawan to 2TS and back. A group of 5 adversarial ships are patrolling around the area of 2TS, split across an eastern, western, and straight on approach. The adversary's mission is to interdict the shipping vessels and disrupt the resupply effort. When an MMRC detects and classifies an adversarial vessel, it begins approaching the vessel at high speeds to both gather more information on their activity and provide theater deception, distracting the adversary from their goal and luring them away. The MMRC Tender and EAB are stationed within the MMRC operating area to provide refueling as necessary, and to provide sensor detection information over communications channels. A sea plane is stationed near the EAB, and after 40 hours begins conducting occasional flights between Palawan and 2TS to provide communications information and refuel for nearby MMRCs. Figure 7 shows a snapshot of the simulation being run.

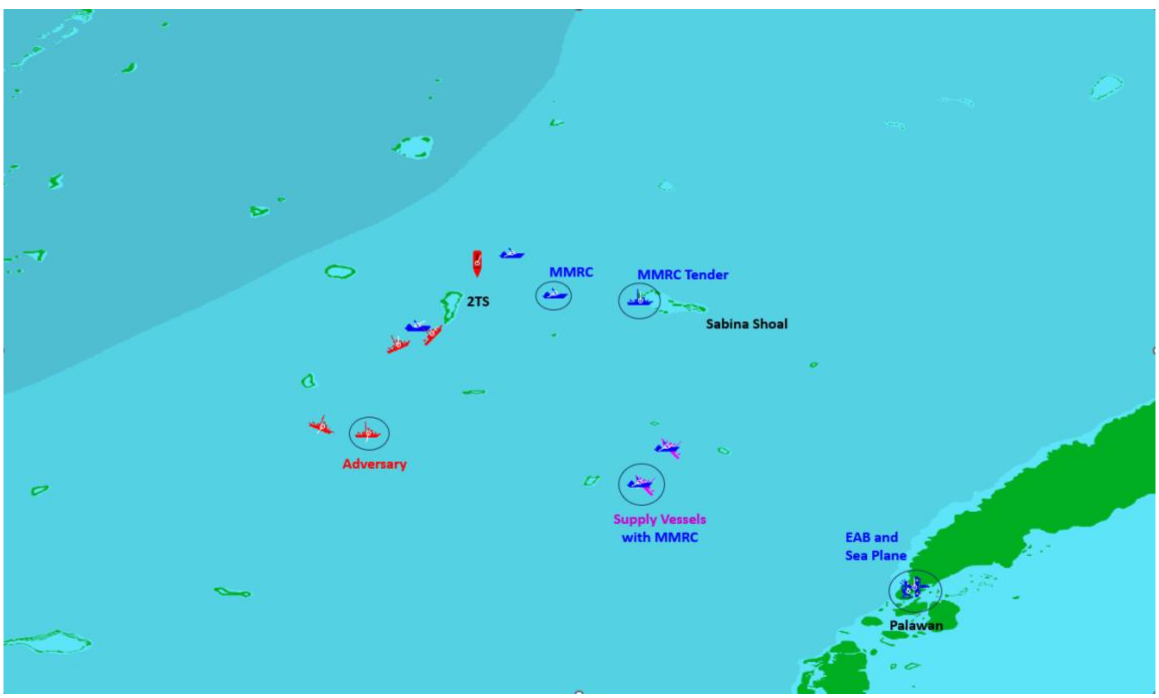

Figure 7. Screenshot of Competition Scenario in MANA

2. Conflict Simulation

This simulation was developed based on the conflict operational scenario described in the first chapter, where the MMRC squadron is deployed to provide ISR and TRAP support for the U.S. Naval forces deployed in an active conflict environment. This simulation takes place over a shorter time span than the competition scenario, ending after

24 hours have elapsed. Three pairs of MMRCs are out in specific areas for patrols, providing intelligence on the adversarial ships prepared to engage in combat with any ships entering the 2TS and Sabina Shoal area. The MMRCs are also prepared to provide TRAP support for any aircraft pilots that are downed during combat. Once the MMRC has conducted the rescue mission, the injured pilot is brought to the Tender for further care and transport. In this scenario the MMRCs are more avoidant of adversarial contact, only approaching to engage in combat when necessary. Figure 8 shows a snapshot of the simulation in progress.

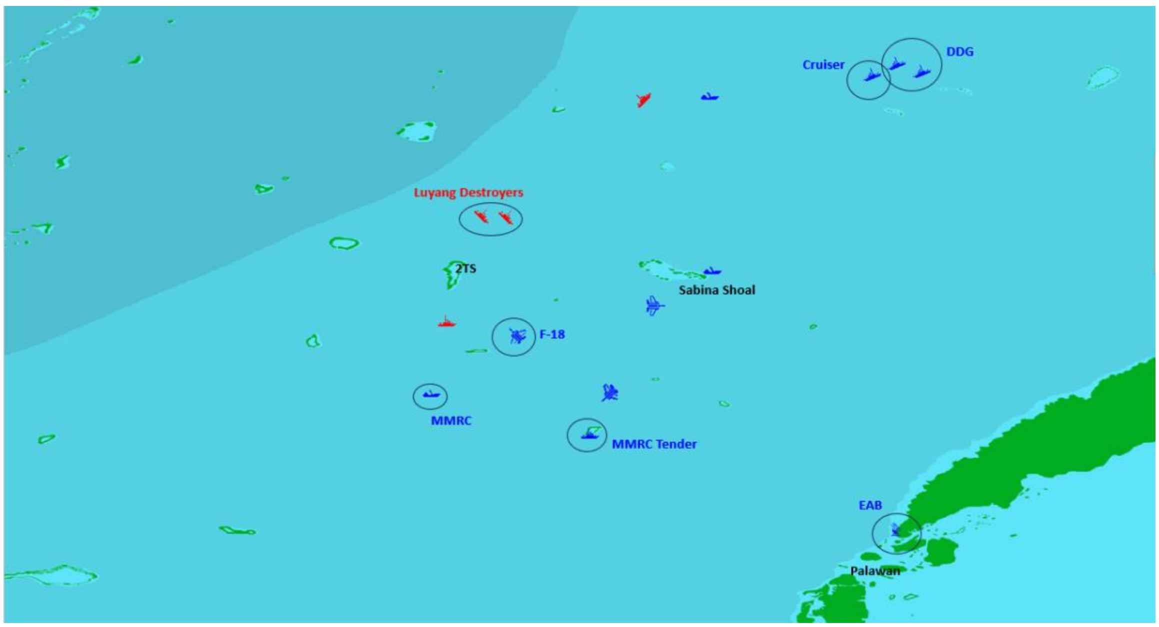

Figure 8. Screenshot of Conflict Scenario in MANA

C. SIMULATION RESULTS

A description of the design of experiments used, as well as a complete and detailed discussion of the extensive simulation analysis for each of the two scenarios can be found in Humphries et al. (2023). A summary of these results show emergence of several themes. In competition, the best results all seem to conclude that having an excellent radar system through high-sensor classification levels and larger aperture arcs contributed to mission success and could be an important design parameter. In conflict, radar values also proved to be significant, along with overall durability through the number of hits the MMRC could take before being 'killed.' This suggests some value could be found in using durable materials for MMRC construction, or ensuring the design is difficult to detect for attack. There was also a trend that having more MMRCs present in the area contributed to a higher rate of adversary detections, higher rate of successful TRAP missions, and in some cases increased the MMRC survivability rate. Finally, the MOE that proved to have both the best fit for regression analysis and most impactful factors for both scenarios turned out to be the number of adversary detections.

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IV. SUMMARY AND FUTURE WORK

A. SUMMARY

As a conclusion and summary of this research, the research questions proposed in section 1 are reviewed below. A brief review is provided to address the most significant insights for each question.

- *How well do the proposed composition and capabilities of Ellis-Class MMRC squadrons prevent adversary interference in partner nation littoral territory?*

Since this is a proposed system, it was necessary to develop an understanding of the system and develop the two different scenarios outlined in order to outline the different missions within each scenario and how each element within the system interacts. From this, three main MOEs were identified for each scenario. For the competition scenario, these MOEs were number of adversarial detections, number of successful convoy resupply missions, and percentage of time spent in pursuit of the adversary. For conflict, the chosen MOEs were the number of adversarial detections, percentage of successful TRAP missions, and percentage of MMRC survivability. Each MOE ties into specific missions for the scenario but overall reflects the ability of the squadron to prevent, deter, disrupt, or reduce adversary incursions into a partner nation's littoral territory. The simulations were run and successfully captured results for the MOEs, allowing us to gauge the overall system effectiveness.

- *What MOEs best represent the achievement of success in the employment and operations of Ellis-Class MMRCs in an operational scenario?*

While each MOE provided its own insight into the interactions of the system, the MOE that proved to have both the best fit for regression and most impactful factors for both scenarios turned out to be the number of adversary detections.

- *What are the significant design decisions and operational parameters for the Ellis-Class MMRCs that provide the largest impact to the MOEs in complex, relevant and timely operational scenarios?*

As described in the analysis summary from the previous chapter, radar capabilities such as radar classification range and aperture arc consistently showed up as a significant factor either alone or as part of factor interactions, showing how important these factors are for the overall success of the squadron's missions.

B. FUTURE WORK

While the three most relevant MOEs for each scenario were chosen, many other MOEs may provide valuable insight into the operation of the MMRC squadrons. Some of the additional MOEs that could be captured using our existing simulations include the number of adversaries defeated in a conflict scenario, the percent of time an adversary spends within the defined LOA for the ally, the number of data transmissions that occur between the MMRCs and other entities such as the EAB, and the amount of time between detection and classification of an adversary.

Another recommendation would be to add more functionality to the existing models, such as support for the functions that were defined but not included in the simulation. This includes anti-submarine warfare, focused collection operations, and more in-depth coordination with partner nation forces. Also, adding UAVs into the simulation to get a clearer picture of their impact on mission success could also provide insight.

Additional research addressing logistical difficulties would require the development of simulations using higher fidelity models that can simulate the impacts of weather and sea state on squadron performance. Our simulation was unable to model weather at all and could only simulate sea state in a very basic, static manner. Both of these environmental factors can have a large impact on performance and should be considered for more in-depth analysis.

Finally, there could be benefits to simulate the impacts of counter-measure support from the MMRCs in conflict missions. The MMRCs in our simulations were only equipped with basic machine guns for combat support, but there was a potential interest in seeing what the impact would be if the MMRC was equipped with the ability to intercept incoming adversarial attacks.

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LIST OF REFERENCES

Anderson, Mark. 2013. “Agent-Based Modelling in the New Zealand Defence Force.” In *Proceedings of the International Defense and Homeland Security Simulation Workshop 2013*, edited by Agostino Bruzzone, Wayne Buck, Francesco Longo, John Sokolowski and Robert Sottilare, 61–66. Rende, Italy: Curran Associates, Inc.

Beery, Paul, and Eugene Paulo. 2019. “Application of Model-Based Systems Engineering Concepts to Support Mission Engineering.” Systems 7 (3): 44–58. https://doi.org/10.3390/systems7030044.

Berger, David. 2021. “Preparing for the Future: Marine Corps Support to Joint Operations in Contested Littorals.” *Military Review Online Exclusive.* April 2021. https://www.armyupress.army.mil/journals/military-review/online-exclusive/2021-ole/berger-future/

Humphries, Tabitha R., Jacob C. Laake, Andrew A. Pompeii, Anna Switzer. 2023. *Ellis Class Multi-Mission Reconnaissance Craft Squadrons in Competition and Conflict*. Systems Engineering Capstone Report, Monterey: Naval Postgraduate School.

Inter-Op. 2023. “Whiskey Multi Mission Reconnaissance Craft.” https://inter-op.ca/whiskey-mmrc/

Joint Chiefs of Staff. 2019. *Competition Continuum*. JDN 1-19. Washington, DC: Joint Chiefs of Staff. https://www.jcs.mil/Portals/36/Documents/Doctrine/jdn_jg/jdn1_19.pdf

Lusczynski, Brian. “Hard to Find, Impossible to Ignore: Proposed Concepts to Persist and Prevail in the FD2030 Operating Environment.” PowerPoint Presentation, May 2, 2022.

Marine Corps. 2021a. *A Concept for Stand-in Forces*. Washington, DC: Marine Corps. https://www.hqmc.marines.mil/Portals/142/Users/183/35/4535/211201_A%20Concept%20for%20Stand-In%20Forces.pdf

Marine Corps. 2021b. *Tentative Manual for Expeditionary Advanced Base Operations*. Washington, DC: Marine Corps. https://mca-marines.org/wp-content/uploads/TM-EABO-First-Edition-1.pdf

United States Navy. 2018. “Mark VI Patrol Boat.” January 12, 2018. https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2173363/mark-vi-patrol-boat/

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