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SYSTEMS ENGINEERING CAPSTONE REPORT

**ELLIS CLASS MULTI-MISSION RECONNAISSANCE
CRAFT SQUADRONS IN COMPETITION AND CONFLICT**

by

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December 2023

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IN COMPETITION AND CONFLICT**

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and LT Anna Switzer (USN)

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ABSTRACT

The capstone 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 a MMRC squadron system architecture, which 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 analyzed to determine which metrics were most relevant to evaluate the successful employment of 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, and a design of experiments was developed for each scenario. Regression analysis was conducted on the resulting data for each of the three MOEs in each scenario. 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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LIST OF ACRONYMS AND ABBREVIATIONS

2TS	Second Thomas Shoal
ASW	anti-submarine warfare
CONOPS	concept of operations
COMCARSTRKGRU	U.S. Navy carrier strike group
CRRC	combat rubber reconnaissance craft
DDG	guided-missile destroyer
DOE	design of experiment
EAB	expeditionary advanced base
EABO	expeditionary advanced base operations
ELLIS	expeditionary long-range littoral surface
EEZ	exclusive economic zone
FMF	Fleet Marine Force
HF	high frequency
ISR	intelligence, surveillance, and reconnaissance
KIG	Kalayaan Island Group
LOA	Littoral Operations Area
LPD	landing platform dock
LRUSV	long range unmanned surface vessel
MANA	Map Aware Non-Uniform Automata
MBSE	model-based systems engineering
MMRC	Multi-mission Reconnaissance Craft
MOE	measures of effectiveness
MOP	measures of performance
M-RXR	Marine reconnaissance and counter reconnaissance
NOLH	nearly orthogonal Latin hypercube
PRC	People's Republic of China
SCS	South China Sea

SIF	stand-in forces
SLOC	sea lines of communication
SysML	systems modeling language
TRAP	tactical recovery of aircraft and personnel
UN	United Nations
UNCLOS	United Nations convention on the law of the sea
U.S.	United States
USMC	United States Marine Corps
UAV	unmanned aerial vehicle
UUV	unmanned underwater vehicle
VHF	very high frequency
WEZ	weapon engagement zone

EXECUTIVE SUMMARY

In order to further realize the fuller vision of the Force Design 2023, the United States Marine Corps has striven to revolutionize both the organizational parameters and operational focus of the Corps throughout recent years. Among these foundational changes are both the development of a force dedicated to “the concepts of littoral operations in contested environments and expeditionary advanced base operations (EABO)” as well as operational use of such a force to enable “naval and joint force commanders as a dedicated multi-domain reconnaissance and counter reconnaissance force” (Berger 2021). As the concept of EABO has matured the corresponding need for stand-in forces (SIF) composed of smaller, distributable, lower signature, and more affordable amphibious ships to enable operations in the area surrounding the network of EABO has come to the forefront. One proposed solution to this pacing need is a formation of Multi-mission Reconnaissance Craft (MMRC) squadrons that would operate from or in conjunction with expeditionary advanced bases (EAB).

This capstone project analyzes the deployment of a baselined MMRC squadron design within the parameters of a potential scenario in order to aid in the development and analysis of functional and operational parameters of the MMRC squadrons and determine which design factors may be considered most relevant in their concept of employment. To achieve this end, the project team employed a custom, mission-focused version of the systems engineering V process model that allowed for the assessment of the MMRC squadron in light of the desired capabilities stipulated by the given mission. Throughout this process, architecture of the MMRC squadron was developed to define the functional and operational use of the MMRC squadron within a Littoral Operations Area (LOA). Various measures of effectiveness (MOE) were identified and then analyzed to determine the metrics most relevant to a successful employment of the MMRC squadron, and the functional and operational parameters which carried the most weight were determined.

Utilizing the Map Aware Non-Uniform Automata (MANA) program, simulations were developed for a subset of MMRC squadron missions in both competition and

conflict scenarios. MANA was then used in conjunction with both simulations to generate Nearly Orthogonal Latin Hypercube (NOLH) designs of 33 design points that altered a total of seven factors for the competition scenario simulation and six factors for the conflict scenario simulation, each design point run with 30 replications for a total of 990 runs per scenario. All resulting data underwent regression analysis to determine which factors had significant impacts on the performance of the MMRC squadron. The resulting analysis found that radar classification range and aperture arc as well as MMRC durability proved to be significant factors in successful MMRC squadron employments.

References

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

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I. INTRODUCTION

A. BACKGROUND

Throughout the entirety of *Force Design 2030* General David H. Berger, Commandant of the Marine Corps, outlines a planned monumental shift in both the organizational parameters and operational focus of the United States Marine Corps (USMC). Chief among these foundational changes in future force development is the updated requirements of a force dedicated to “the concepts of littoral operations in contested environments and expeditionary advanced base operations (EABO)” (Berger 2021).

To prepare for potential future scenarios of conflict with peer adversaries, the USMC is considering the role they may have to play in “enabling naval and joint force commanders as a dedicated multi-domain reconnaissance and counter reconnaissance force.” Such a role differs inherently from the large-scale amphibious forcible entry and sustained operational role General Berger argues “has persisted unchanged in its essential inspiration since the 1950s” (Berger 2021). A new force design calls for the capabilities of littoral maneuver and persistent operability within range of adversary long-range fires. The concept of 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 area of the network of EABO.

One aspect of Gen Berger’s 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 capstone 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.

B. OPERATIONAL SCENARIO SCENE-SETTER

Second Thomas Shoal (2TS), known as “Ayungin Shoal” in the Philippines, is in the Kalayaan Island Group (KIG) of the Spratly Islands in the South China Sea (SCS). The United States Indo-Pacific Command provides the following background information about 2TS:

It sits approximately 104 nautical miles from the archipelagic baseline of the Philippine island of Palawan within the Philippines’ exclusive economic zone (EEZ). In 1999, the Philippines grounded BRP SIERRA MADRE (LT-57), a Philippine Navy transport vessel, on 2TS where it remains as a Philippine military outpost. In 2016, a United Nations (UN) Arbitral Tribunal convened in accordance with United Nations Convention on the Law of the Sea (UNCLOS) determined that the Philippines possesses sovereign rights to resources at 2TS and that the People’s Republic of China (PRC) has no lawful territorial or maritime claim to 2TS. The PRC has failed to recognize the UN Arbitral Tribunal’s binding ruling, Philippine sovereign rights, and fundamental principles of international law, such as freedom of navigation, due regard, and rules for navigational safety by continuing to interfere with the Philippines’ activities in and around 2TS, including lawful operations to resupply Sierra Madre and its detachment of Philippine Marines.¹

The Philippine military is seeking to resupply its troops in the Second Thomas Shoal, but Chinese Coast Guard vessels have repeatedly used shouldering and water cannons to harass and turn back civilian boats bringing supplies to the soldiers. Additionally, the PRC has recently announced its intention to conduct a combined exercise in the Spratly Islands, and intelligence indicates this could involve assets from their military installations on Fiery Cross Reef and Mischief Reef, that could include fighter/attack aircraft, surface vessels, and potentially ballistic missile launches. The Philippine navy has requested United States (U.S.) assistance in providing reconnaissance/counter-reconnaissance, scouting, and maritime security for a resupply mission on Second Thomas Shoal for the BRP SIERRA MADRE.

¹ USINDOPACOM Joint Operational Law Team (J06.pacom@pacom.mil) Last Updated: 23 Feb 2023 (all prior versions obsolete) **This TACAID includes legal opinion and analysis that does not necessarily reflect official U.S. government positions.

C. RESEARCH OBJECTIVE

In today's evolving threat environments and those of the near future, the need for smaller but capable assets possessing littoral maneuver capabilities has become increasingly more operationally relevant. The overall mission outlined in the scenario is to employ stand-in forces comprised of MMRC squadrons for operational use within the adversary's weapons engagement zone (WEZ). The U.S. objective in both the competition and the conflict scenarios modeled in this research is to use these MMRC squadrons to identify, track, deter and deny adversary incursions into partner nation littoral territory and international waters.

The focus of this capstone is to assess 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 a 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 MOEs were explored and analyzed to determine which metrics were most relevant to evaluate the successful employment of the MMRC squadrons. Lastly, this research was intended to determine what functional and operational parameters carry the most weight when considering the capabilities of the MMRCs as well as the MMRC squadrons. This capstone answers the following 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 measures of effectiveness (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 measures of effectiveness in relevant and complex operational scenarios?

D. SYSTEMS ENGINEERING PROCESS

For this capstone project, the Stand-In Squad focused on utilizing model-based systems engineering (MBSE) techniques to provide a mission engineering analysis for the operations of the MMRC squadrons. Utilizing the principles for integrating MBSE into mission engineering efforts as discussed in Beery and Paulo (2019), the team developed a tailored Vee process model to guide this project as shown in Figure 1. 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.

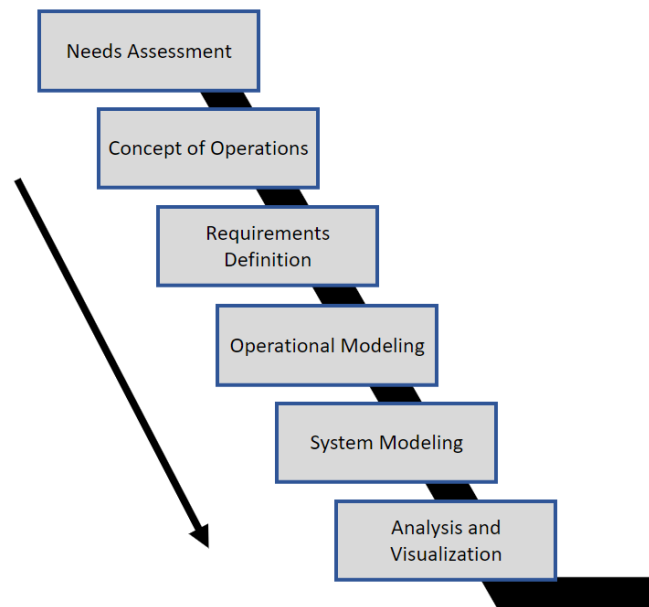


Figure 1. Systems Engineering Process

The process began with the Needs Assessment phase, where the literature review provided previous research done in relation to SIF and littoral operations. Conversations with the sponsor resulted in a more refined identification of requirements and

expectations. This was followed by the Concept of Operations (CONOPS) phase, in which the problem definition was defined through the development of mission scenarios that meet the stakeholder's intent for the system. Context and OV-1 diagrams were developed to provide visualization of the system of interest and its operational intent. In the Requirements Definition phase, the system requirements were derived from the defined stakeholder needs and refined to align with the stakeholder needs and context. These requirements were illustrated in a system modeling language (SysML) requirements diagram.

This was followed by the Operational Modeling phase, where the functional operation of the system was defined utilizing various SysML models such as activity diagrams, sequence diagrams, and use case diagrams. Once the functional architecture was determined the System Modeling phase began, during which the physical system components needed to achieve the desired functionality of the operational model were defined using block definition diagrams. The final stage was the System Analysis phase, during which information from the various SysML models was synthesized to develop operational simulations of the MRRC squadron mission. Utilizing the simulations, the team designed an experiment to analyze which system design and operational employment factors have the greatest impact on the measures of effectiveness for the system.

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II. LITERATURE REVIEW

Team Stand-in Squad reviewed several online sources and documents provided by the sponsor to understand naval concepts and practices that take place when dealing with adversaries and potential threats. The information gathered provided insight on the current state of naval forces and capabilities as well as adversary tactics and practices.

A. STAND-IN FORCES

Stand-in forces 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 in close proximity to an adversary which 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. These stand-in forces are intended to shape the forward operational environment gathering intelligence, conducting surveillance, and contributing to the denial of emerging threats (Marine Corps 2021a).

B. EXPEDITIONARY ADVANCED BASE OPERATIONS

The Chief of Naval Operations and the Commandant of the Marine Corps 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). Missions of EABO include supporting sea control operations, conducting sea denial operations within littorals, contributing to maritime domain awareness, as well as providing forward capabilities and sustainment (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 (Marine Corps 2021b). An expeditionary advanced base is stationed within an adversary's 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).

C. COMPARABLE CAPABILITIES

While the Ellis-Class MMRC does not yet exist, there are multiple existing craft with capabilities that meet many of the identified requirements. These vessels include the Mark VI patrol boat, the Whiskey MMRC, and the Marine Corps' latest long range unmanned surface vessel (LRUSV) with a Hero-120 kinetic weapon system attached. 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), well suited to perform the intended Stand-In Forces missions in littoral areas. That said 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).

The Australian Whiskey MMRC has been touted as a “game-changing” low signature “Sense First, See First, Strike First” craft that integrates cutting-edge maritime technologies, such as systems, sensors, and effectors, with tactical networks and situational awareness tools already in use by the United States military (Inter-Op 2023). This MMRC class features a workable deck-space, increased payload, and exceptional mobility and maneuverability.

D. COMBATANT CRAFTS

There are three types of combatant craft used by the U.S. Navy Special Warfare Command: Combatant Craft Assault (CCA), Combatant Craft Medium (CCM) Mk1, and Combatant Craft Heavy (CCH) SEALION. The CCA is a high-speed, highly agile watercraft operated by Special Boat Teams to primarily conduct special operations, coastal patrol operations, and medium range maritime interdiction operations in medium-to-high threat environments (American Special Ops 2023a). The CCM is a surface tactical mobility craft designed to provide insertion and extraction capabilities for special

operations forces in low-medium threat environments (American Special Ops 2023c). It is a low observable, reconfigurable craft that also has limited fire support, can carry out maritime interdiction, conduct visit board search and seizure missions, as well as counter terrorism and foreign internal defense operations (American Special Ops 2023c). The CCA and CCM crafts will be smaller, lighter, and faster than the MMRC, but their high levels of maneuverability will be considered when proposing potential design decisions to the MMRC.

The CCH, the largest craft of the three, has a primary role of long-range insertion and extraction of Navy SEALs in medium-to-high level environments while also having the capabilities to launch and recover a combat rubber raiding craft (CCRC) to support maritime interdiction as well as limited coastal patrol operations (American Special Ops 2023b). This craft will be the same length as the MMRC but lighter in displacement. Recognizing the design features, characteristics and capabilities of these various craft contributed to design considerations for the Ellis-Class MMRC.

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III. PROBLEM SCOPE

A. STAKEHOLDER ASSESSMENT

The team began stakeholder assessment by taking an all-encompassing view of the different parties impacted by the implementation of MMRC squadrons. The initial stakeholders had varying degrees of interest and expectations and need to be further scoped within the expectations of this capstone. Table 1 shows the stakeholders that have the most interest in the operational aspects of the MMRC squadron, alongside their primary needs and concerns. Each stakeholder is identified by their overall role, with specific individual roles listed underneath. The adversarial nation is included as a stakeholder to ensure the team was seeing both sides of the assessment, since understanding the adversaries' objectives, capabilities, and tactics is important when trying to thwart them. Each stakeholder is classified as either primary or secondary stakeholders based on their level of involvement in the decision-making process. The primary stakeholders are more directly involved with the MMRC, whereas the secondary stakeholders will be affected by the implementation of the MMRC squadron.

Table 1. Stakeholders of MMRC Platform and Operations

Stakeholder	Type	Primary Need	Concerns
Customer U.S. Department of the Navy (U.S. Marine Corps and U.S. Navy)	Primary	Implementation of a Stand-in Force in the littoral maritime environment to prevent adversary interference. Ability to operate in support of U.S. Naval vessels and objectives.	Logistics and support required to field MMRC squadrons. Interoperability and communication of the MMRC with partner forces and U.S. Naval Vessels.
Operators/Warfighters MMRC Crew/Recon Team/EOD Dive Teams/ NSW Group 4	Primary	Ability to utilize Ellis-class MMRCs in operational scenarios. Implementation of training and tactics.	Survivability, repairability and ease-of-use of MMRC while underway.

Stakeholder	Type	Primary Need	Concerns
			Proper training is provided.
Allies/Partners Partner Nations and Joint Forces	Secondary	Ability to receive intelligence without risking own troops. Avoidance of conflict scenarios with adversarial nations. Ability to operate jointly in support of partner nations, allied forces, and U.S. Naval operations. Ability to utilize in support of campaign plans and operational objectives.	Operation of MMRC within their territorial waters. Potential of provoking conflict with adversary by partnering with U.S. Integration and interoperability between partner nations, allied forces, U.S. Navy, and Marine Corps. Maintainability of the MMRC and supporting infrastructure.
Adversarial Nations	Secondary	Ability to assert power into other nation's littoral spaces without detection or interference.	Loss of ability to assert influence on territory. Potential of provoking multi-nation conflict.

B. NEEDS ANALYSIS

While several sources were reviewed in relation to the potential employment of MMRC squadrons in operational scenarios, the main source referenced when developing the needs and functionality of the MMCR squadron system was the slide presentation from a May 2022 lecture, “Hard to Find, Impossible to Ignore,” given by the team’s primary Marine Corp sponsor Lieutenant Colonel Brian Luszczynski. 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 team was able to identify the following four major capabilities 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 Tactical Recovery of Aircraft and Personnel (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 the capstone 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 2 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 chapter.

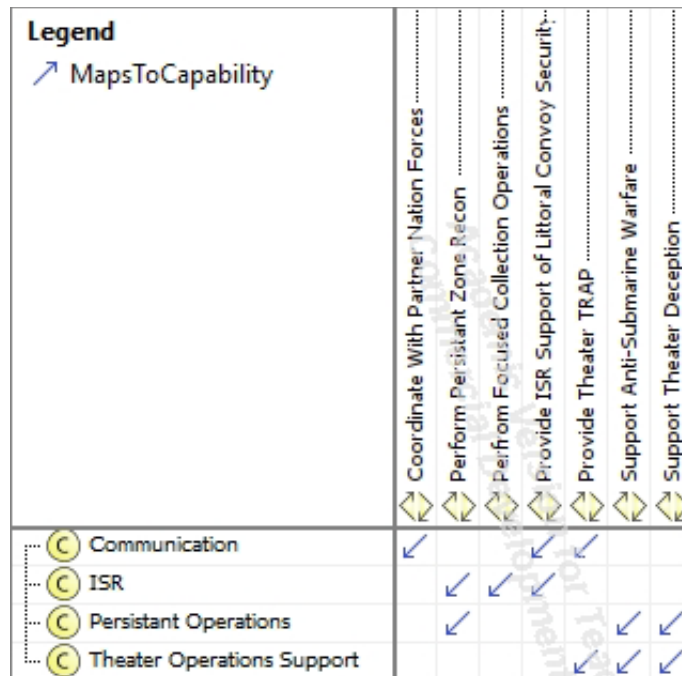


Figure 2. Capability Matrix Mapping

Throughout the “Hard to Find, Impossible to Ignore” (Luszczynski 2022) slide presentation there is mention of the potential for missile firing capability to be added to the MMRCs, providing the potential for MMRCs to defeat adversarial vessels. After conversations with the stakeholder, the team received clarification that this capability is not currently under consideration for the initial MMRC squadron implementation. In accordance, this capstone does not implement missile fire in the models or simulations of the MMRC squadron, instead reserving the capability for a potential future modeling and simulation excursion.

C. OPERATIONAL SCENARIOS

“Hard to Find, Impossible to Ignore” (Luszczynski 2022) defined two distinct roles for the employment of MMRC squadrons, categorized by the current operational environment. In a competition below 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). While there are major capabilities shared across each environment, the overall mission for the MMRC squadron changes. Due to this, the team decided to develop a unique mission scenario for each of the two environments, each built in the context of the overarching background scenario. 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 Philippine Navy and Marine Forces on Palawan Island. The U.S. Navy will deploy a task group under the SEVENTHFLT Commander. The task group will be assigned to LOA Cyclone under either a Marine Corps 1 star or a Coast Guard 2 star. MMRC Groups, composed of 4x MMRC squadrons, will be deployed to support USMC Stand-In Forces. Each squadron will be responsible for specific areas surrounding areas of interest. MMRC squadrons will be deployed from the Expeditionary Advanced Base (EAB), consisting of 1x Seaplane, 1x MMRC Tender, and 6x MMRCs. MMRC squadrons will be equipped with an assortment of unmanned reconnaissance vehicles. MMRC's will be configured for reconnaissance and self-defense with the ability to reconfigure at the Expeditionary advanced bases (EABs). Alongside Philippine Forces, they will conduct persistent zone recon in the assigned area of the LOA. Combined Maritime Patrols will be conducted to support Philippine maritime territorial integrity activities within the Philippine EEZ and territorial waters, and to provide ISR for U.S. and Philippine forces. The Stand-In Forces will 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 will meet the Commander's Intent of maintaining freedom of navigation, territorial integrity, and protecting sea lines of communication (SLOC) while also maintaining awareness of PRC movements and pattern of life. Figure 3 shows an OV-1 diagram highlighting the operations undertaken in this scenario.

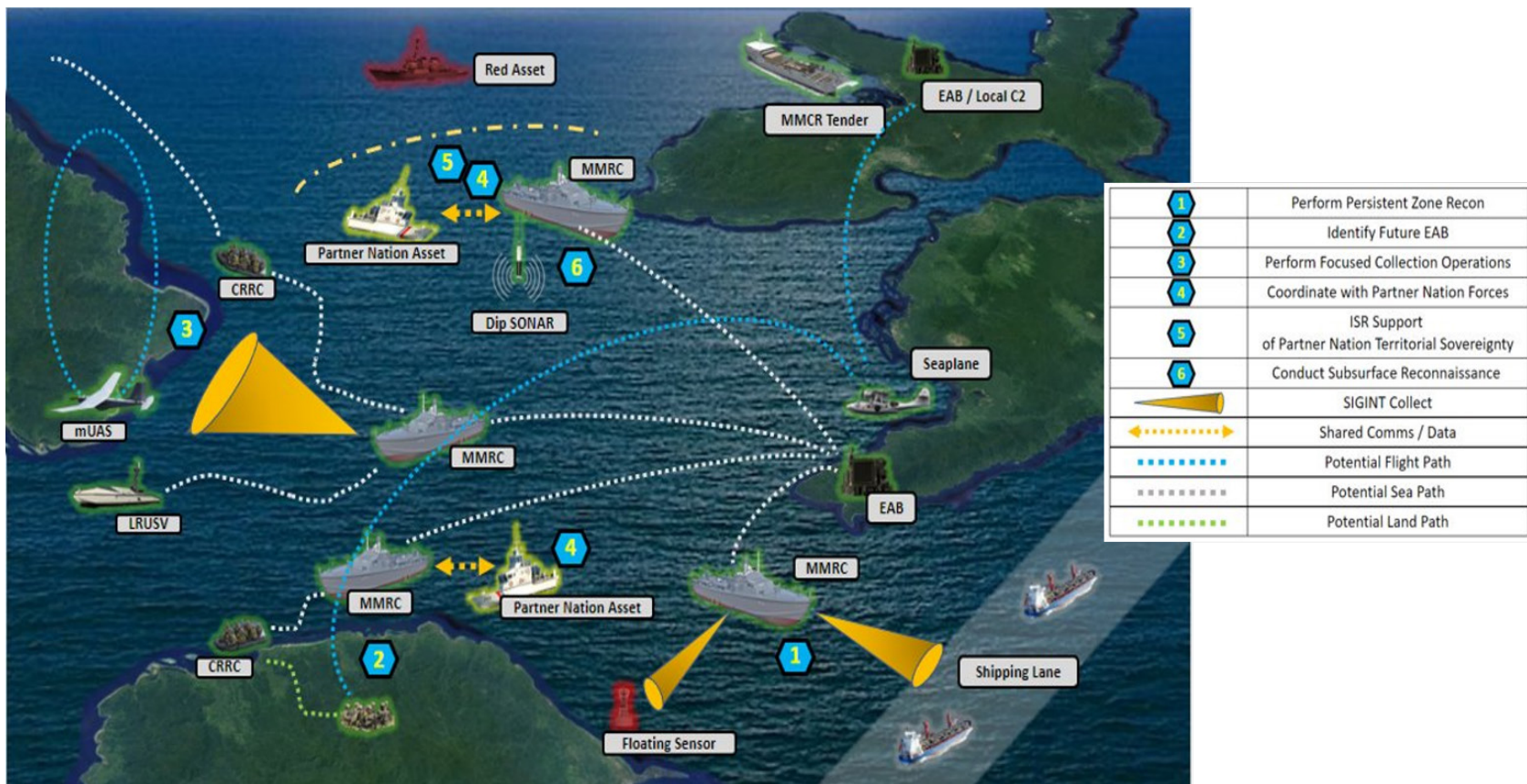


Figure 3. OV-1 for MMRC Squadron Operations in a Competition Scenario

2. Scenario B: Armed Conflict

The PRC 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 will 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 Stand-In Forces will enable Joint Forcible Entry Operations, including maritime convoy scouting and screening, insertion of EAB teams, support to contested amphibious landings, LOA TRAP, and to provide 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 will meet the Commander's intent of controlling SLOCS, enabling naval maneuvering, marine littoral operations, and joint access throughout LOA Cyclone. Figure 4 shows an OV-1 diagram highlighting the operations undertaken in this scenario.



Figure 4. OV-1 for MMRC Squadron Operations in a Conflict Scenario

D. CONTEXT DIAGRAM

Once the needs of the system and specific scenarios were determined, the team then developed the context diagram shown in Figure 5 to define the composition of our system of interest and with which outside entities it interacts. This diagram also has aspects of an input/output diagram, showing the interactions between entities. The system of interest is the MMRC Squadron System, which includes six MMRCs, a tender, and a sea plane all working together to conduct the mission. The mission holds a central role within the system, as it is a defining force on how the squadron will interact. Depending on which mission is underway, different components of the system will be utilized and the number of MMRCs engaged will differ. For example, the MMRC has the capability to launch a Combat Rubber Reconnaissance Craft for land-based recon and scouting activities. The squadron can also deploy several types of UxVs based on the mission to gather recon data from the surface, undersea and the air.

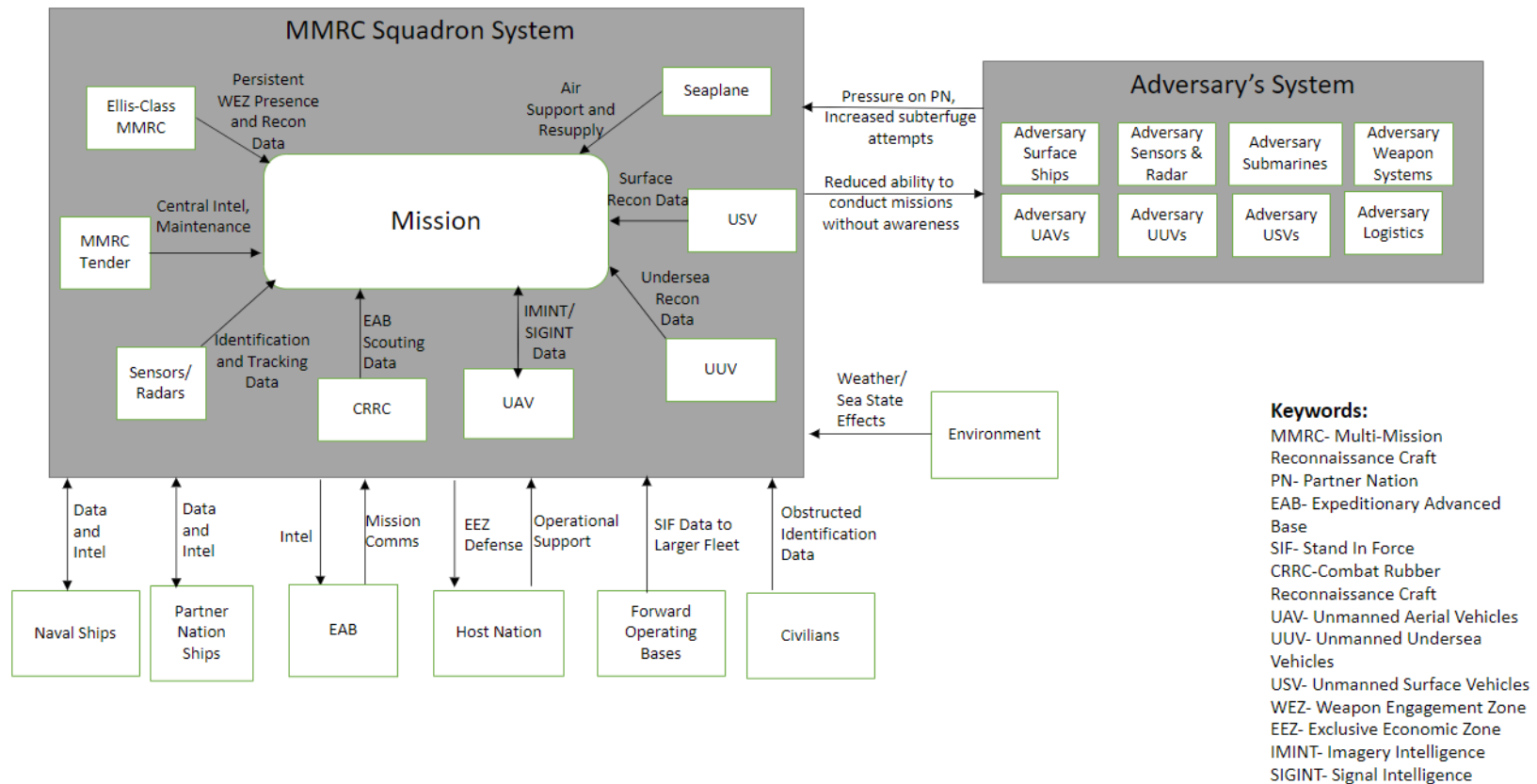


Figure 5. MMRC Squadron System Context Diagram

The main external interaction of interest is between the MMRC squadron and the adversarial system, which consists of a variety of ships, UxVs and sensors. The squadron is most concerned with identifying and tracking the actions of the adversary and subverting their attempts to exert pressure upon the partner nation. Also of primary interest is the squadron's relationship with the host nation, providing operational support to the mission while the squadron works to defend its exclusive economic zones and territorial claims. The squadron will work closely with U.S. and partner nation naval assets, providing frequent communication and intel as necessary. They will also maintain close communication with the EABs to exchange mission updates and to provide intelligence reports, which will be further disseminated by the forward operating bases. Finally, the squadron must be cognizant of environmental factors and civilian movement, both of which can impede the squadron's movement.

E. PHYSICAL SYSTEM COMPOSITION

Since many of the individual components of the MMRC squadron are still in high level concept stages, the team focused the physical composition 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 6.

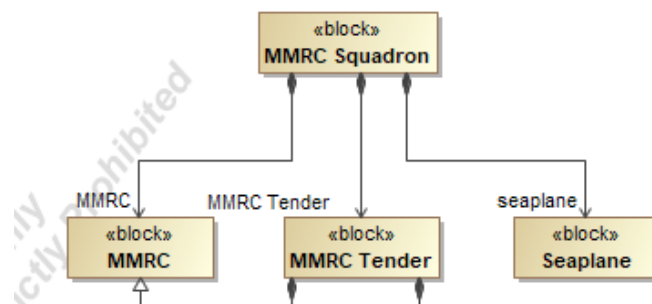


Figure 6. Top Level Physical Composition of MMRC Squadron

The MMRC squadron is composed of the MMRCs, one MMRC Tender, and one sea plane. Figure 7 breaks down the physical composition of the MMRCs.

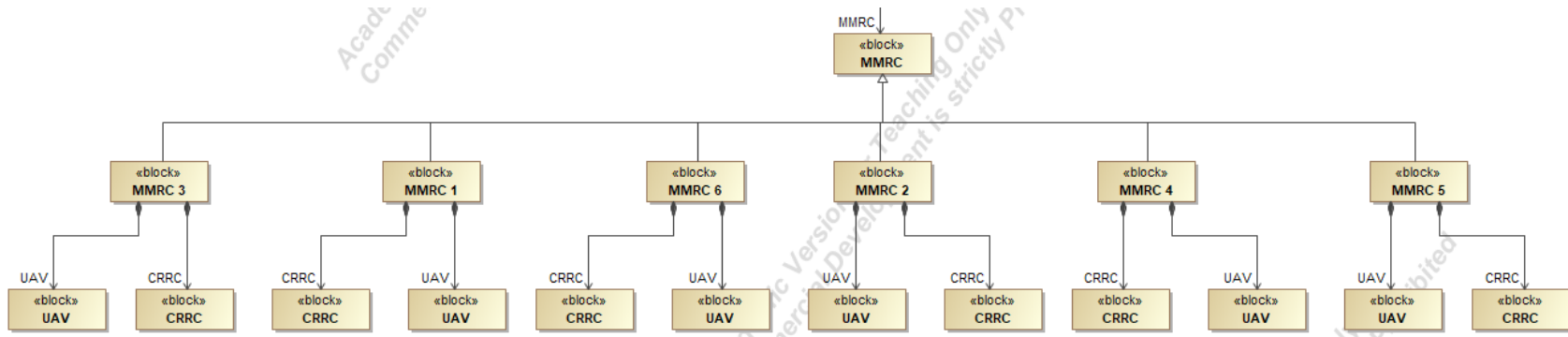


Figure 7. MMRC Physical Breakdown

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 recon and identifying and reporting potential future EAB sites. The breakdown of the MMRC Tender is shown in Figure 8.

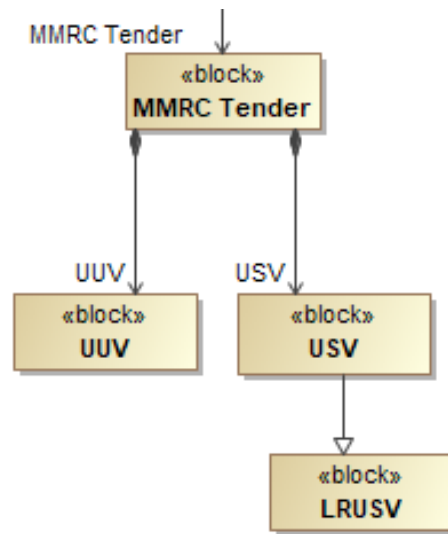


Figure 8. MMRC Tender Physical Breakdown

The MMRC Tender will carry at least one UUV and USV, specifically an LRUSV. Like the UAV and CRRC, the UUV and LRUSV will also be prepared and deployed to assist in key functionalities of persistent zone recon.

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IV. PROBLEM DEFINITION

A. REQUIREMENTS ANALYSIS

Once the major system capabilities and stakeholder needs were defined, the team was able to conduct a requirements analysis to define the functional requirements for the MMRC squadron system. The team analyzed proposed operational vignettes provided by the sponsor in “Hard to Find, Impossible to Ignore” (Luszczynski 2022) to identify the major functional capabilities that fell within each of the four major capabilities defined in the needs assessment. Some requirements apply only in the competition or conflict scenario, while others branch into both. Table 2 shows each of the high-level functional requirements that were identified, listed with the capability from which it was refined. All MMRC squadron functionality developed and analyzed through this capstone project traces back to one of these major system requirements.

Table 2. Requirements as Defined per Capability

Capability	Requirements
Persistent Operations	The system shall be able to maintain persistence presence within the zone in competition scenarios.
ISR	The system shall be able to conduct zone recon and focused collection operations in competition scenarios. The system shall provide ISR support to U.S. and partner nation littoral convoys in conflict scenarios.
Theater Operation Support	The system shall have the capability to conduct theater TRAP operations in both competition and conflict scenarios. The system shall have the capability to conduct theater deception operations in both competition and conflict scenarios.
Communication	The system shall facilitate coordination efforts between U.S. and partner nation forces in competition and conflict scenarios.

B. FUNCTIONAL ANALYSIS

Through information provided by the sponsor and consolidated during the literature review, a functional analysis was conducted that yielded the functional hierarchy of operational activities depicted in Figure 9. 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 secondly, to show the relationships between the system requirements and the parameters of the CONOPS.

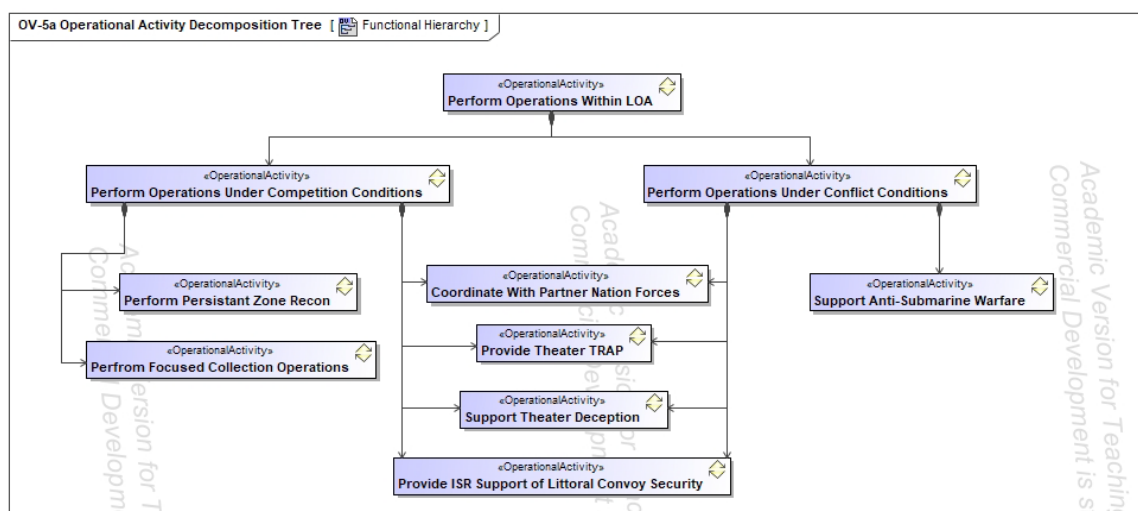


Figure 9. Functional Hierarchy

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 MMRCs 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.

Additional steps of the functional analysis included the generation of activity diagrams depicting top level views of selected sub-functions, their internal functional makeup and flow. The construction of these diagrams allowed the team to consider how the MMRCs would accomplish their assigned tasking both individually and as a Squadron. Four of these activity diagrams served as the foundation from which the dynamic simulations were built and are detailed in length here. Due to the scope of this project, activity diagrams were not developed for the remaining three sub-functions, leaving this work for future study. The first decomposed sub-function, Performing Persistent Zone Recon, is shown in Figure 10.

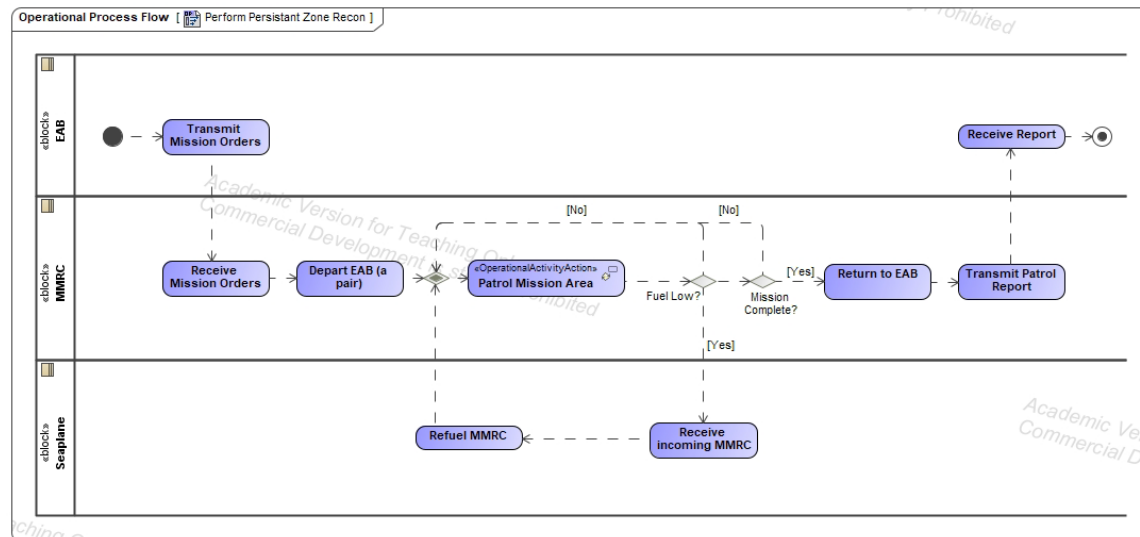


Figure 10. Perform Persistent Zone Recon Activity Diagram

While performing persistent zone recon the key action of the MMRC squadron is a patrol of a specified mission area. This operational activity action consists of several distinct operations from placing floating sensors for increased area awareness, to performing recon on specific elements detected within the mission area. These operations internal to Patrol Mission Area are further broken down into their own diagram, as shown in Figure 11, and depict how the MMRC is mainly concerned with gathering intel on land-based activity, ships and sensors. This coincides with this commander's intent, per the scenario, to maintain awareness of PRC activity within the region.

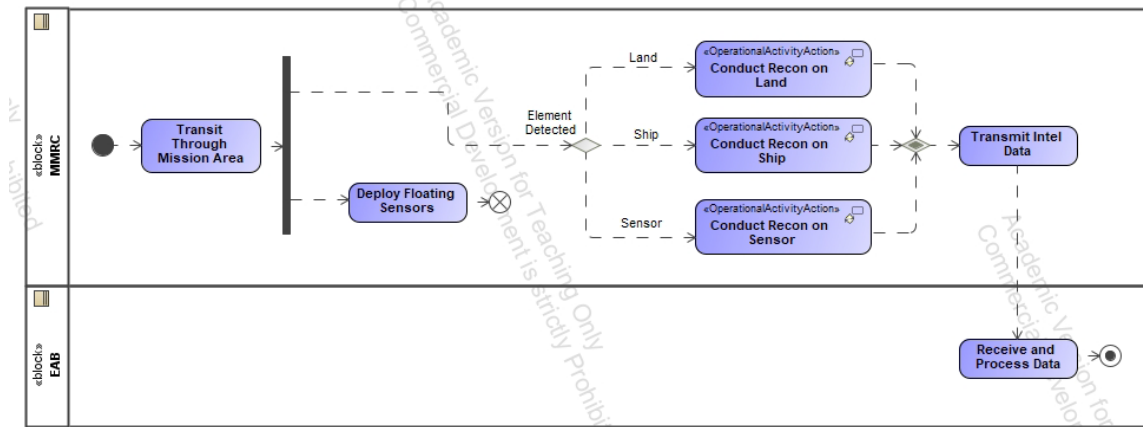


Figure 11. Patrol Mission Area Activity Diagram

For further clarification, and to assist with the requirements of the dynamic simulation, the operational flow of Conduct Recon on Land, Conduct Recon on Ship, and Conduct Recon on Sensor were each depicted in distinct diagrams shown in Figure 12 through Figure 14. In each activity the focus is to utilize any available resources to gather pertinent information about the element being identified and ensuring that the information is provided back to the EAB for operational awareness.

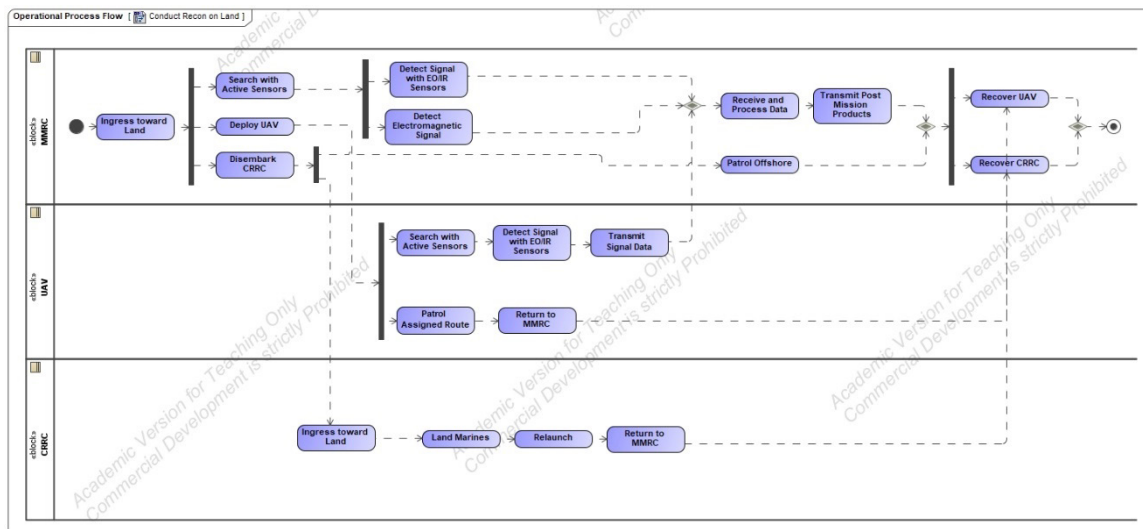


Figure 12. Conduct Recon on Land Activity Diagram

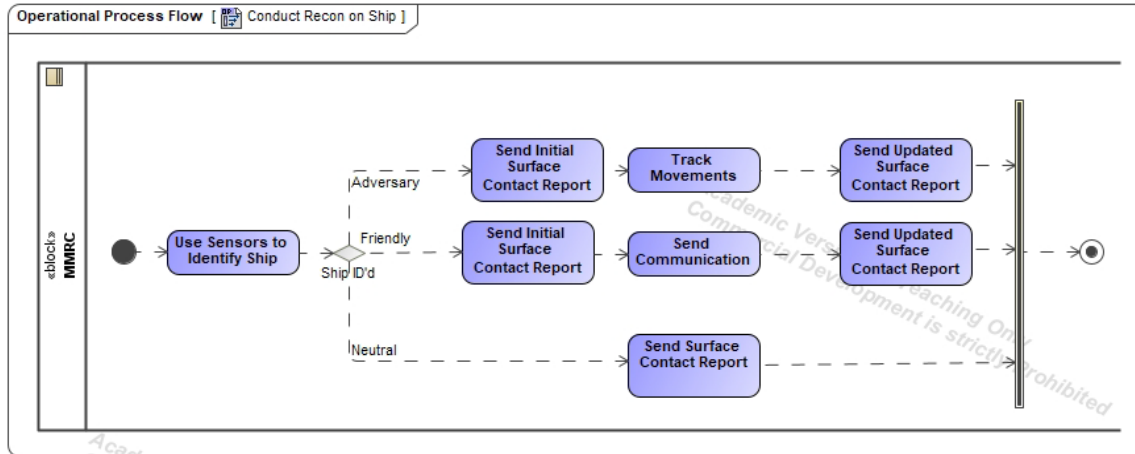


Figure 13. Conduct Recon on Ship Activity Diagram

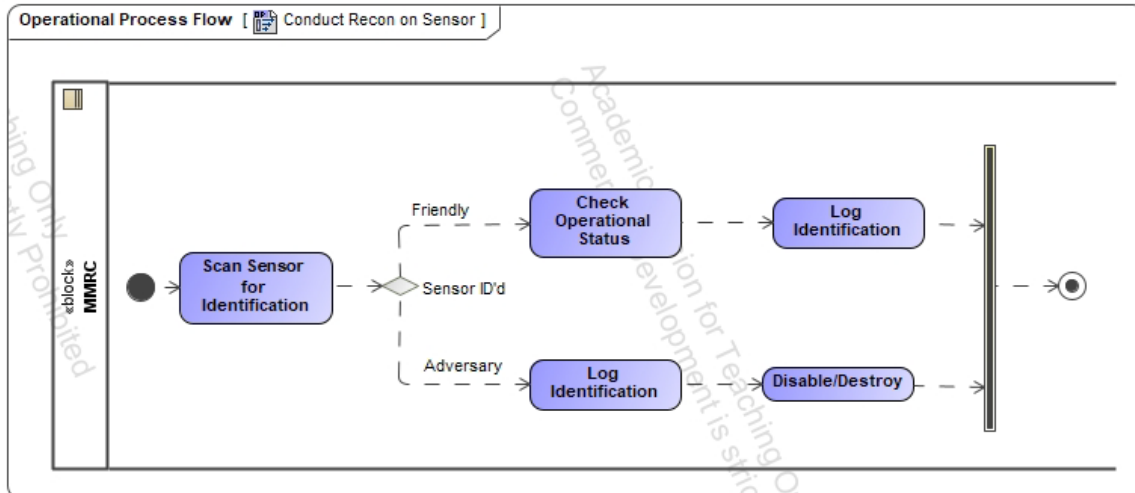


Figure 14. Conduct Recon on Sensor Activity Diagram

These diagrams do not depict the actions of the entire MMRC squadron, rather each operational flow would serve as a mission tasked to an either a pair of MMRCs, or an MMRC in tandem with a partner nation asset. Additionally, although each individual operational flow within the subfunction Performing Persistent Zone Recon could potentially be performed simultaneously, it is envisioned that each operational flow would instead be independently assigned and carried out as the demands of the broader mission of the MMRC squadron and the operational availability of MMRC assets dictate.

The next sub-function decomposed is Provide Theater TRAP, as shown in Figure 15. This operation depicts at least two MMRCs from the squadron tasked with locating and rescuing personnel in distress such as a downed pilot. Both MMRCs work in tandem to search the area for the source of the distress signal. Once located, one MMRC engages in the rescue and relocation of the personnel; in the presence of any wreckage, the other MMRC would remain with this wreckage to deter the adversary from attempting a recovering. The MMRC transporting the personnel would link up with the seaplane which would then transport the personnel either to the EAB, or to another location to link up with Joint Forces for further EVAC.

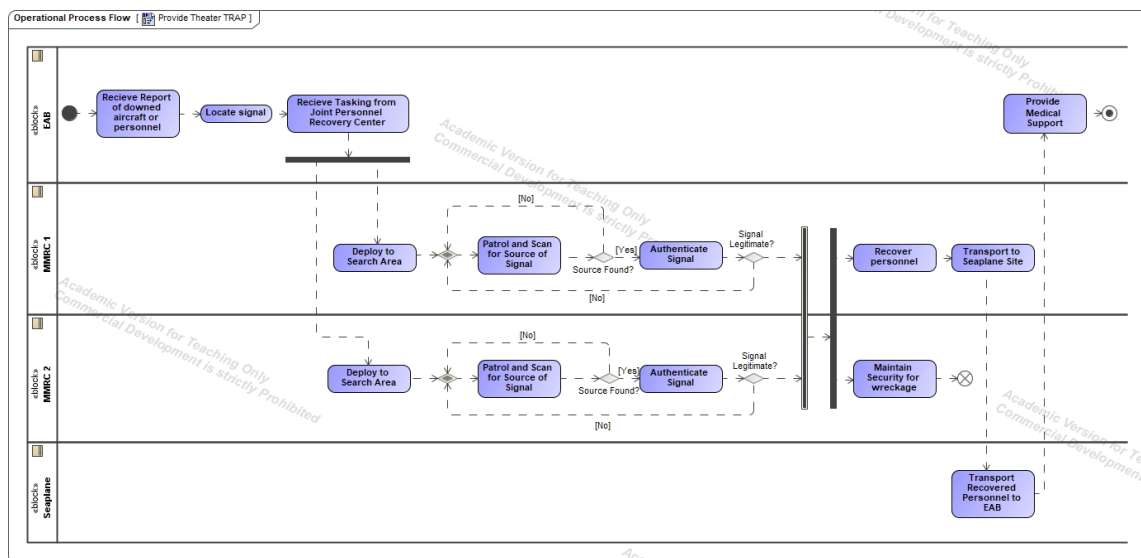


Figure 15. Provide Theater TRAP Activity Diagram

In Figure 16, the sub-function Support Theater Deception is decomposed. The flow illustrates the two primary ways the MMRC squadron will contribute to larger theater deception missions. One, by towing an emitting barge or array to spoof an L-class ship and lure the adversary from their initial target, or two, by setting up an emitting device on some landmass to spoof the location of an EAB. It is envisioned that either variant of this mission would be assigned to a pair of MMRCs and most likely serve as a supporting mission to some larger Joint Force effort of a distinct, simultaneous MMRC

mission such as Performing Focused Collection Operations or Providing ISR Support of Littoral Convoy Security.

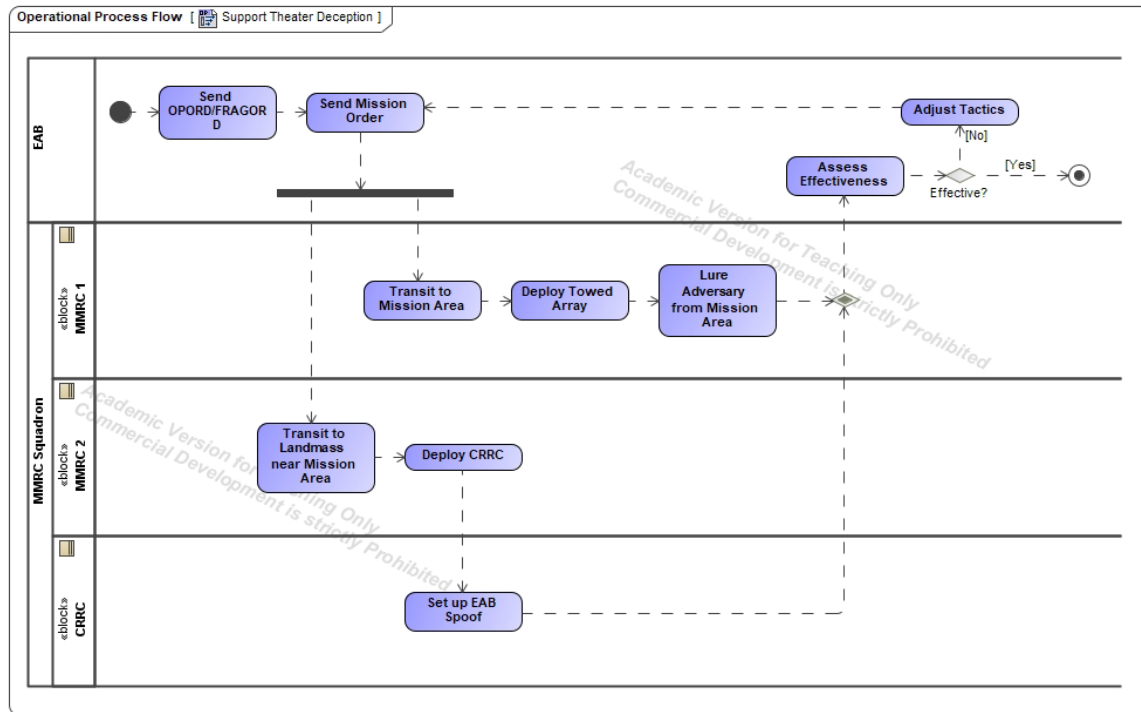


Figure 16. Support Theater Deception Activity Diagram

The last sub-function decomposed in relation to the dynamic simulations was Provide ISR Support of Littoral Convoy Security. As shown in Figure 17, this diagram depicts the steps and methods an MMRC could employ to provide such support. Depending on the loadout of a given MMRC, various UXVs could be deployed from or in tandem with the MMRC to extend the effective area that MMRC is monitoring for the sake of early warning provided to the Littoral Convoy Security.

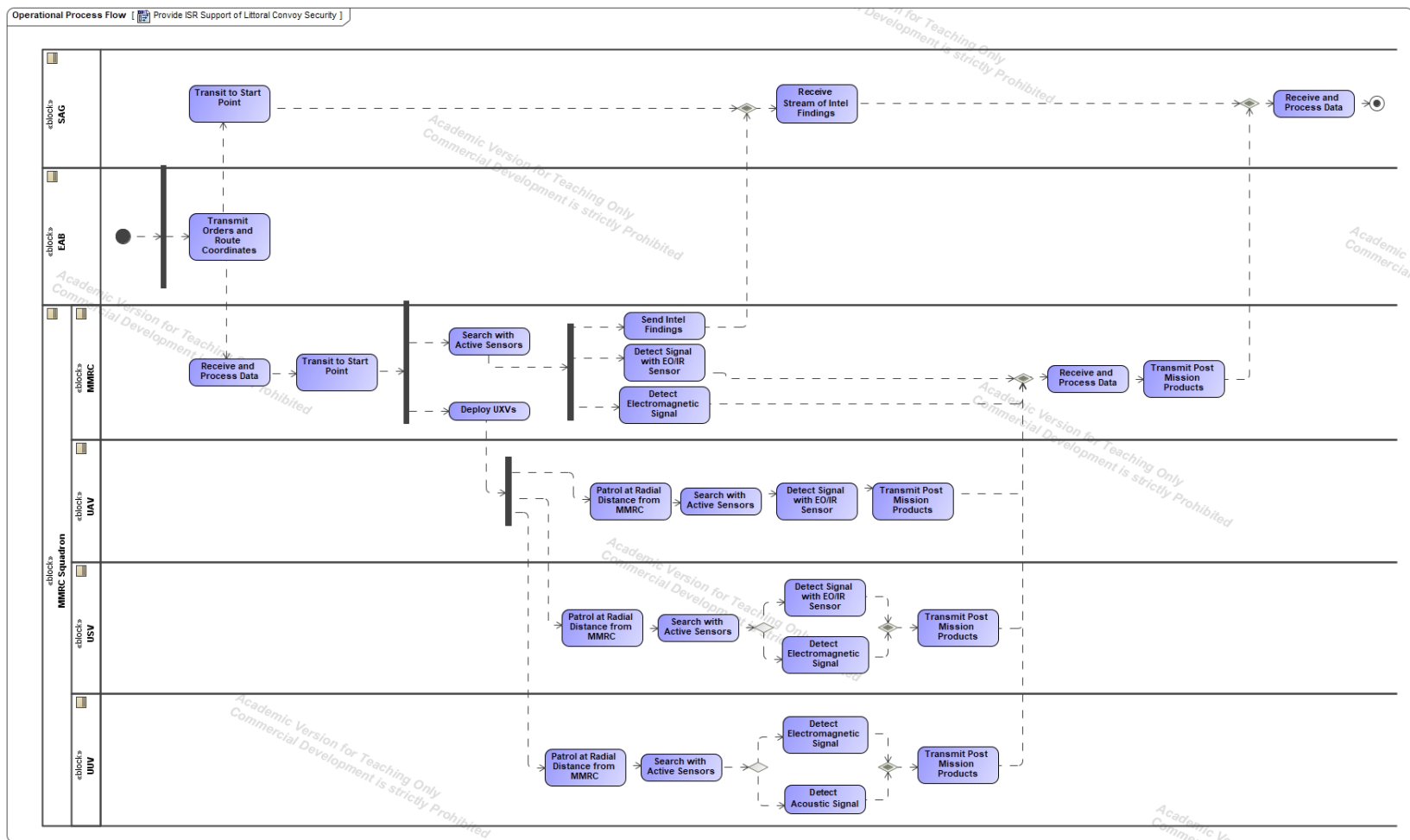


Figure 17. Provide ISR Support of Littoral Convoy Security Activity Diagram

C. PERFORMANCE METRICS

To determine how successful the MMRC squadron may be at accomplishing the missions outlined in the functional activities above, it was necessary to identify some quantifiable measures that could be gathered related to each mission. The team reviewed each of the activities from the functional analysis to determine what steps could provide tangible data to measure effectiveness and performance of the system. MOEs were defined for both the competition and conflict scenario to aid in quantifying the success of the outcome for the scenarios. There are some overlapping measures between the scenarios as competition and conflict will have similar functionalities and needs.

1. Competition Measures of Effectiveness

Table 3 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 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 3. 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 4 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 4. 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

V. MODEL DESCRIPTION

A. SIMULATION SOFTWARE

After reviewing several different simulation software tools, the team choose to utilize a tool developed by the New Zealand Defense Technology Agency called Map Aware Non-Uniform Automata (MANA). MANA was developed as an agent-based modeling environment, which allows each agent in the simulation to move autonomously within the bounds of the characteristics and behaviors defined by the user. This allows the simulation developer to view the potential interactions between different agent groups and to thereby discover potential emergent behaviors that can develop from these relationships (Anderson 2013). The tool can run multiple iterations of a scenario with relatively quick run times, which means data for multiple different scenarios can be gathered in a timely manner (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. ASSUMPTIONS AND LIMITATIONS

When developing a simulation, decisions must be made about what level of fidelity is sufficient to answer the intent of the model. A higher fidelity model can provide more realistic results but can be extremely complex to build and take a large amount of computing power to execute. The MANA tool has a wide variety of options for simulating the behaviors of agents but does have limitations on the amount of detail that can be added to the simulation. Keeping in mind the limitations of MANA and the primary goal of assessing the effectiveness of the MMRC squadron, the team made the following list of assumptions when developing our simulations:

- Weather conditions can have an impact on many model parameters, such as speed, maneuverability, and sensor detection capabilities. Given the

limitations of MANA, weather conditions were considered to be clear with normal visibility.

- For sea-based simulations, sea state is another factor that can impact speed and maneuverability. For these simulations the sea state was modeled by having specific areas with more difficult to traverse terrain, however these locations were static and did not dynamically change over time as seen in real situations.
- While MANA allows users to define elevation maps and has an option for flying agents to ignore all terrain, there are not well defined ways to differentiate between surface and sub-surface movement. With that in mind, the simulations were built with a focus on surface platforms.
- MANA provides a variety of states that an agent can transition into when specific conditions are met, and the user can define unique behaviors when an agent transitions into a new state. The duration of a state is determined mainly by a user defined time, which can be randomized to any value up to the time defined. Once the state has reached its allotted time, the agent will immediately transition to the next defined state unless another state is triggered in that time. The time periods for each state in the simulation were chosen by the team as best-guess estimates.
- This capstone is being conducted at an unclassified level, and therefore is using publicly available approximations for values such as sensor and weapon ranges. Values that could be classified such as probability of kill at different ranges are not factored in for weaponry, instead assuming an 100% probability of kill at an available average range.

C. AGENTS

This section outlines each of the different assets modeled in the simulations, with general information on their composition. Images showing the full range of baseline simulation parameters for each agent in its default state can be found in Appendix A.

1. MMRC

The MMRC is one of the key agents of the simulation and is based on the suggested Ellis-Class MMRC design outlined in “Hard to Find, Impossible to Ignore” (Luszczynski 2022). Since the design is at a high-level conceptual stage, the team had to use available data on comparable components to build out the specifications for the MMRC. The documentation suggests the use of a commercial maritime radar for sensing, so all sensor values were derived from the assumption of a Furuno DRS-NXT series radar (Furuno 2023). Based on the design, each MMRC can reach a maximum speed of 35 knots, and the general patrol speed was decided to be around 10–12 knots. The MMRCs are equipped with three 1000-gallon fuel tanks and three 1000 horsepower maritime engines. Given the 80-foot size of the craft, the overall amount of fuel was determined to be around 2000 gallons and fuel burn was calculated using average values for known maritime engines.

The MMRC will use SATCOM for communication needs. In the event there are SATCOM-denied conditions, the MMRC will use very high frequency (VHF) and high frequency (HF) communications. In the event VHF communications are used, the transmission range for an MMRC will depend on the radio power, current terrain, and the antenna size (Cobra 2023). This results in less communication ranges between the MMRCs but will be greater when communicating with the MMRC Tender, due to its higher antenna, and the EAB, due to it being a well-equipped station. In the event of Comm-denied conditions, the MMRC will use alternatives such as physical dispatch/messenger missions and UAS carrier-pigeon missions in which the UAS can physically transport the data to a destination. For this simulation no ballistic weaponry will be

modeled on the MMRC, but they will be equipped with M240B 7.62mm machine guns to be used in the conflict scenario (Luszczynski 2022).

2. MMRC Tender

The MMRC tender serves as a station for maintenance, rearming and refueling while underway on the mission. The tender will remain as a stationary headquarters, located off the Sabina Shoal in the waters surrounding Palawan. This allows the MMRCs to persist in the LOA for longer periods of time, without having to return to the EAB for basic maintenance tasks. In the simulations, the tender's primary role is to provide refueling to any friendly agent that comes within the necessary refueling range. The MMRC tender will use the same forms of communication as the MMRC. However, when using VHF communications, the tender will be able to transmit and receive messages at a greater distance due to having a greater sized antenna compared to the MMRC. The sensor for the tender will be based off a landing platform dock (LPD). The sensors include an AN/SPQ-9B surface radar for ships and other surface contacts and an AN/SPS-48C air search radar for any airborne contacts (Pike 2000).

3. Sea Plane

The sea plane serves as a platform to resupply and refuel the MMRC's while underway. The United States does not currently have any sea planes in its inventory, so a commercial option was considered when developing factors for this agent. The Daher Kodiak is very customizable and adaptable to many missions, so it can be utilized as a sea plane and fits perfectly for the MMRC resupply mission. The sea plane will launch from a supply location and fly to a designated location to rendezvous with an MMRC. Once the two platforms have connected, the sea plane will be able to transfer food, parts, equipment, medical supplies, mail, ammunition, and other supplies to the MMRC crew and conduct refueling operations with the MMRC. The sea plane is expected to be an easily configurable platform and therefore also able to conduct medical evacuation (MEDEVAC) operations as needed. Although the sea plane is easily configurable, it will be ill prepared to support high-risk operations in a contested environment.

4. EAB

The expeditionary advanced base will be a stationary, land-based location set up and managed by a USMC Battalion Landing Team and Logistics Combat Element in approved host nation locations. They will contain robust support equipment including cranes, dry dock, armorer, small part production capability, fuel farms, and medical personnel. MMRC's will be able to conduct both maintenance, resupply, and refueling at these locations. These locations can also serve as the staging location for the sea plane.

Depending on how the USMC wants to equip the EAB's, they are expected to have a heavy support package. There will USMC organic tactical UAS which will support force protection efforts with various cameras that are electro-optical and infrared capable. The Marines will also bring a wide range of sensors, radios, and weapons. Communication items will range from various radios to telephone sets, to computer terminals. The EAB will also be equipped with several types of radar for surface and aerial coverage. For force protection, the Battalion Landing Team will come equipped with various calibers of machine guns, 60mm and 81mm mortars, and Javelins.

5. Adversary Ships

a. Competition

Within the Competition Scenario, the adversary agents were based off of the China Coast Guard (CGC) Zhaoyu class patrol cutters. At 3,450 tonnes and 110 meters, these ships represent the mid-range size of CGC vessels and is slightly smaller than the larger CGC Zhaotou class or the PLAN Jiangkai class frigates (Global Security 2021). For the dynamic simulation, the Zhaoyu class agents were modeled as both operating at a greater speed and operating with a greater sensor range than the MMRCs. Neither kinetic weapons nor water cannons were explicitly modeled on these platforms, rather the effects of such means were modeled implicitly through specifying the personalities of the agents. As such, the Zhaoyu class agents were modeled with the propensity to actively

move toward Philippine supply vessels but away from challenging MMRC agents.

b. Conflict

Within the conflict scenario, the adversary agents were based on larger PLAN vessels including Luyang class destroyers and Jiangkai class frigates. In accordance with the characteristics of these ships, both the allowable cruising speed and the sensor ranges were increased in comparison to the Zhaoyu class patrol cutters. Both classes of ships operate VLS cells capable of firing anti-ship missiles, surface-to-air missiles, and anti-submarine missiles; only the former of which is in use due to the scope of this scenario (Naval Technology 2017).

6. U.S. Naval Forces

In the conflict scenario, two guided-missile destroyers (DDGs) a cruiser and four F-18 combat crafts are deployed out in the waters surrounding Palawan. These assets have broken off from a COMCARSTRKGRU, transiting ahead to provide anti-ship warfare support. Active communication with the MMRCs gives the assets advanced warning on approaching adversaries for earlier engagement. If an aircraft is downed during combat, the MMRCs will deploy to provide TRAP support for the pilot.

7. Partner Nation Ships

The partner nation forces are shown in the competition scenario and consist of Philippines supply vessels, whose primary goal is to deliver supplies from Palawan to 2TS. The ships travel at roughly 12 knots and are pre-disposed to move away from interacting with the adversarial forces. These vessels are not armed, and specifics on sensors and communications were not modeled for the sake of these simulations.

D. SIMULATIONS

The simulation map covers a 200 nm x 200 nm area off the western shore of Palawan, Philippines that encompasses 2TS and several other smaller reefs and shoals in the area. 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 state are represented by differing shades of blue, with it being more difficult to traverse in the darker shades of blue than in the lighter shades. Figure 18 shows the terrain map utilized for the simulations.

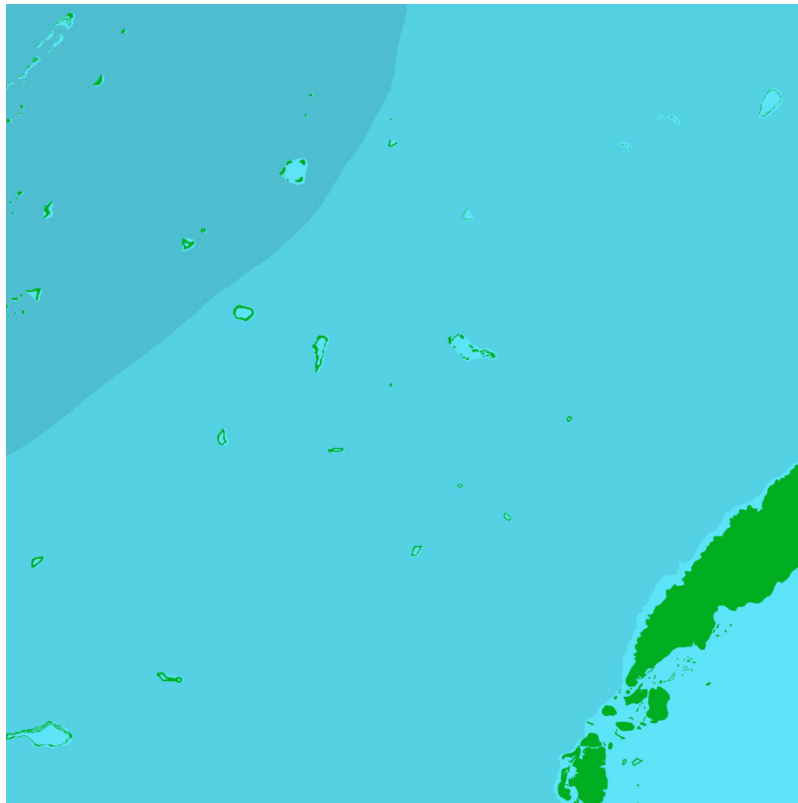


Figure 18. Terrain Map Utilized for MANA Simulations

1. Competition

This simulation was developed based on operational scenario A as described in Chapter III, in which the MMRC squadron is deployed to provide scouting and defense for Philippines shipping vessels attempting to conduct a series 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 19 shows a snapshot of the simulation in the progress of being run.

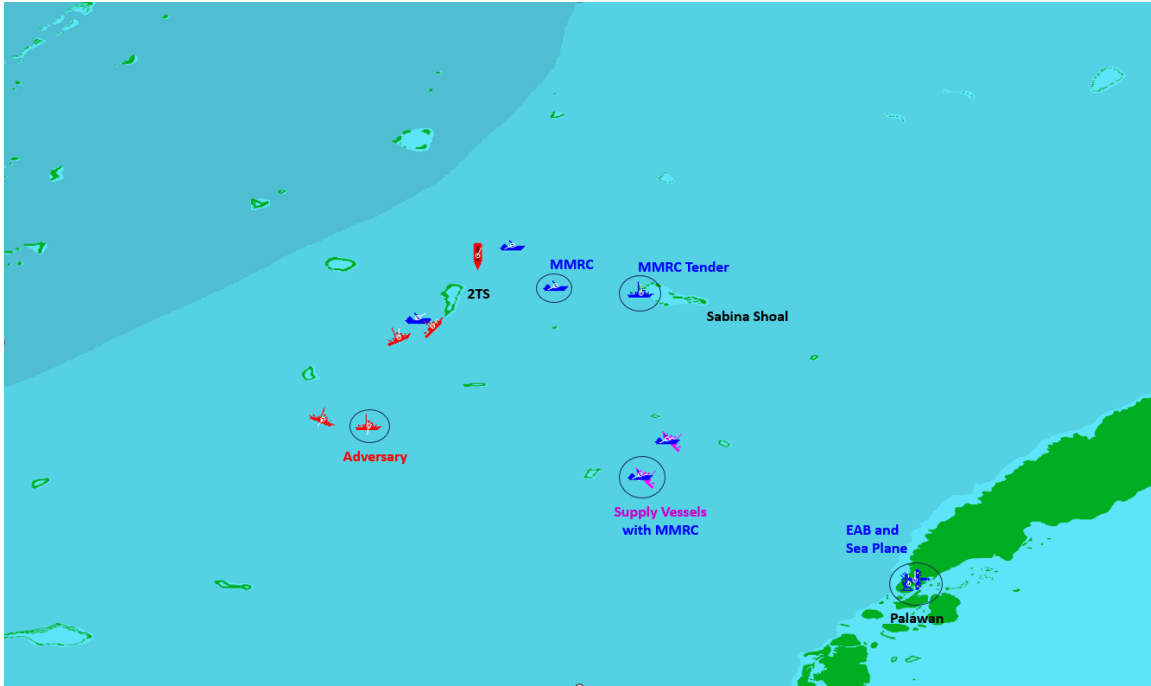


Figure 19. Screenshot of Competition Scenario in MANA

2. Conflict

This simulation was developed based on operational scenario B as described in chapter three, in which 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 20 shows a snapshot of the simulation in progress.

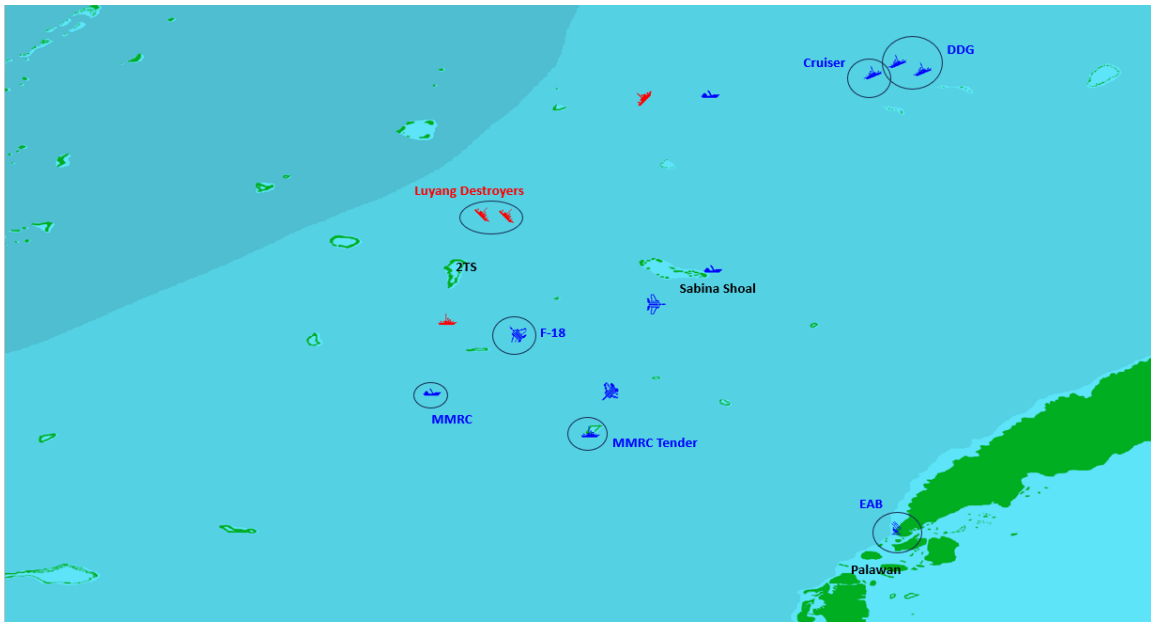


Figure 20. Screenshot of Conflict Scenario in MANA

E. DESIGN OF EXPERIMENT

Once the simulations were established, the team was then able to begin conducting an experiment to gather metrics for the defined MOEs. MANA has a simplified tool for developing simulation experiments called Simple MANA Farmer, which utilizes a Nearly Orthogonal Latin Hypercube (NOLH) design of experiment (DOE) for up to 11 different factors defined by the user. This tool operates using an XML configuration file, which controls setup variables such as the max number of repetitions allowed, the available list of factors to be investigated, and the scenario that will need to be imported and loaded. Once the DOE has been developed, Simple MANA Farmer allows you to run the experiment and collect data automatically through its interface. The tool also allows for the merging of data outputs with the DOE to give a full picture of the results. There is the ability to concatenate information such as casualty location data, agent state data, positions data, detection data, and more along with each run of the DOE. Running an 11 factor NOLH results in a total of 33 unique design points, and our team chose to do 30 replications of each for a total of 990 runs per simulation given restrictions in computing power and data post-processing time.

1. Competition Scenario

Table 5 shows the factors that were chosen for the competition scenario, with the minimum and maximum values defined. The minimum and maximum ranges include the current factor values within the range, to see both the impacts of increasing and decreasing a factor value. Sensor classification range and aperture arc are important factors for determining when the MMRC can properly identify and classify an adversary to gather information and act against them. The number of MMRCs within each patrol area can impact their ability to detect the adversary and deploy effective decoy tactics, with some patrol areas potentially more in need of support than others. The amount of fuel available on each MMRC has an impact on their ability to persist in the LOA and conduct their missions without having to divert to a refueling station. Finally, the current simulation relies on the adversaries having a strong propensity to avoid the MMRCs, so altering the strength of their avoidance reaction could impact the efficiency of the MMRCs. The table showing the factor values used in each iteration of the DOE can be found in Appendix B.

Table 5. Factors for Competition DOE

Factor	Minimum Value	Maximum Value
MMRC Sensor Classification Range	20000 meters	45000 meters
MMRC Sensor Aperture Arc	10°	30°
Number of MMRCs Forward Scouting	1	3
Number of MMRCs Patrolling	1	3
Number of MMRCs in Convoy Protection	1	3
Total Fuel Amount	100000	300000
Level of Adversarial Deterrence	50	100

2. Conflict Scenario

Table 6 shows the factors that were chosen for the conflict scenario, with the minimum and maximum values defined. The minimum and maximum ranges include the current factor values within the range, to see both the impacts of increasing and

decreasing a factor. As in the competition scenario, sensor classification range and aperture arc determine how soon the MMRC can identify and classify an adversary to gather information to send to the U.S. forces. The number of MMRCs within each patrol can impact the number of adversaries detected and availability to provide TRAP support and could impact survivability due to the potential for strength in numbers. The range on the MMRC's M240B machine gun impacts how far away they need to be to engage in conflict, which could impact survivability. The number of hits it takes to kill the MMRC reflects the strength of material used for construction and has a direct tie to survivability. For the final factor, altering the range of the adversary's weaponry could impact their ability to injure the naval assets, which could increase the need for TRAP support. The table showing the factor values used in each iteration of the DOE can be found in Appendix B.

Table 6. Factors for Conflict DOE

Factor	Minimum Value	Maximum Value
MMRC Sensor Classification Range	20000 meters	45000 meters
MMRC Sensor Aperture Arc	10°	30°
Number of MMRCs in Patrol Group	1	3
MMRC M240B Firing Range	1000 meters	2500 meters
MMRC Hits to Kill	2	4
Adversarial MK45 Firing Range	20000 meters	30000 meters

VI. RESULTS ANALYSIS

After running the simulation using the DoE created by Simple MANA Farmer, the team was able to start collecting results for both the competition and conflict scenario. The output consisted of comma-separated values files containing the data for the agent state, the casualty location, positions, and detections for each run. The team determined for each scenario which specific output files contained the data that would provide the result associated with each MOE. Due to the large number of runs conducted for each scenario (i.e., 990 runs each the competition and conflict), python scripts were written to run through the appropriate output files and return the desired MOE value per run. This was done to significantly reduce the time needed to process the data and capture the MOE results. The mean value for the 30 replications was taken as the result for each of the 33 design points. The factors of the design point were then concatenated with the MOE values and inserted into Minitab and JMP, two statistical software tools. Using Minitab, the objective for analyzing the results of each scenario is to identify the most impactful MOEs using various statistical analysis techniques. JMP allowed the team to develop partition trees and determine at what values each impactful factor had the greatest impact. Identifying the most impactful factors for each of the MOEs based on our results will aid in forming recommendations on which factors are most important when considering the MMRC's design.

A. COMPETITION DOE RESULTS

For each of the 990 runs conducted for the competition scenario, the results collected consisted of the number of successful resupply missions to Second Thomas Shoal, the number of adversary detections, and the percentage of time the MMRCs spent pursuing an adversary during the simulation. The chosen DoE factors were compared against each MOE to determine the most important factors to consider when in a competition scenario. The main statistical method used to make conclusions on the data for each MOE was the assessment of the p-value in a hypothesis test. For this test, our null hypothesis is that there is no significant relationship between any of the factors and

the MOE value, while our alternative hypothesis is that a significant relationship exists between any factor and the MOE value. Each analysis is against a 95% confidence interval, inferring a key p-value of 0.05. If any factor has a p-value of 0.05 or less, then the null hypothesis is to be rejected and the alternative hypothesis is accepted. This would state that the factor did have an effect and difference on the outcome. If the p-value is above 0.05 for all factors, then it would infer that the null hypothesis is to be accepted and that no specific factor had a major effect on the results.

1. Successful Resupply MOE

In the competition scenario, the Philippine supply vessels will travel from Palawan to Second Thomas Shoal to resupply the island. A successful resupply occurs when one of the Philippine supply vessels is able to arrive and anchor at Second Thomas Shoal to unload the supplies. To collect the results of the number of successful resupplies that occurred for each run, the python script that was created parsed through the positions file and calculated the number of times a supply vessel agent reached Second Thomas Shoal. For these results, the objective is to maximize the number of successful resupplies.

The results for all 33 design points ranged from an average of 5.13 to 6.00 successful resupplies from Palawan to Second Thomas Shoal by the supply vessels. To begin the analysis of these results, the first statistical technique the team used is regression analysis. As stated before, identifying the factors that have the greatest impact on the outcome of the MOEs is the main objective for the analysis. Regression analysis helps in determining a statistically significant relationship between the independent variables and the dependent variables, and aids in forming predictions on what the results could be based on the values of the independent variables. The coefficients table produced from the regression analysis is shown in Table 7.

Table 7. Coefficients Table for Successful Resupply MOE

Term	Coef	P-Value
Constant	5.104	0.000
MMRCSensorClassificationRange	0.000007	0.074
MMRCSensorApertureArc	0.00901	0.090
NumberofMMRCsForwardScouting	0.0089	0.833
NumberofMMRCsPatrolling	-0.0696	0.117
NumberofMMRCsConvoyProtection	0.0909	0.039
TotalMMRCFuel	0.000000	0.597
RedDeterrence	-0.00037	0.855

From this table, the most important value to note is the p-value. As stated before, the regression analysis was conducted using a 95% confidence interval, suggesting that any p-value at 0.05 or less should be deemed statistically significant. In this case, the number of MMRCs in convoy protection proves to be the most significant factor in this analysis on the results as it has a p-value of 0.039. The null hypothesis for this would be rejected, and the number of MMRCs in convoy protection is assumed to be the only factor to make an impact. The least significant factor in this analysis is the level of enemy deterrence against the MMRCs. This leads to suggesting that potential changes in adversarial tactics would not have a significant impact on this outcome.

Another important outcome from the regression analysis to investigate is the R-squared statistic. This value measures the goodness of fit of a regression model, establishing the variation between the dependent variable and the independent variables. The higher the R-squared value, the more the variability is explained. The model summary with the R-squared statistics is shown in Table 8.

Table 8. R-Squared Analysis for Successful Resupplies

S	R-sq	R-sq(adj)	R-sq(pred)
0.169823	34.97%	16.76%	0.00%

The adjusted R-squared value is 16.76%. This leads to believe that the data did not fit the regression model very well and there is quite unexplained variability in the results based on the changes in the factors. This may be confirmed by their only being one variable, the number of MMRCs in convoy protection, that proved to be significant.

Another statistical technique used to analyze the data was a factorial regression. A factorial regression will provide more insight into which factors, or a combination of factors, were significant on the results. From this technique, a pareto chart of the effects is produced. A pareto chart prioritizes the factors and/or a combination of factors that contribute to the effects of the results. The way the factors are prioritized is from the magnitude that the factors had on the results. This can help address what changes in design could most substantially improve a system. The pareto chart can be seen in Figure 21.

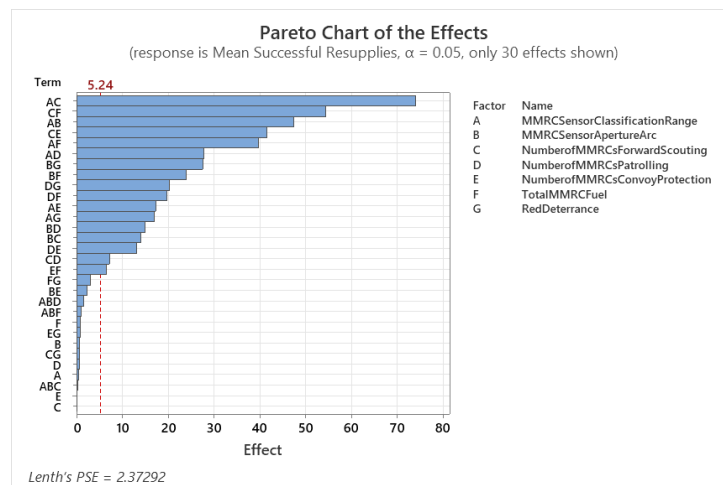


Figure 21. Successful Resupply Pareto Chart

As seen from the chart, the interaction of factors that showed some significance was the sensor classification range and the number of MMRCs in forward scouting, the number of MMRCs in forward scouting and the total amount of fuel in the MMRCs, the sensor classification range and the sensor aperture arc, as well as the number of MMRCs in forward scouting and convoy protection. These interactions showing the greatest effect

on the results can draw conclusions that the focus to maximize these resupplies and ensuring the supply vessel's safe travels averting the adversary can be directed towards having possibly different MMRC group sizes and sensor lengths. A focus on having greater sensor capabilities, as well as shifting the MMRC group sizes in favor of forward scouting and convoy protection in order to identify the adversaries more in advance to deter them from the supply vessels could be significant in increasing the number of successful resupplies to Second Thomas Shoal.

Due to regression analysis and factorial regression showing only certain factors being significant with a lower R-square statistic, the team determined a partition tree would help further evaluate the most significant factors. The partition tree can be seen in Figure 22.

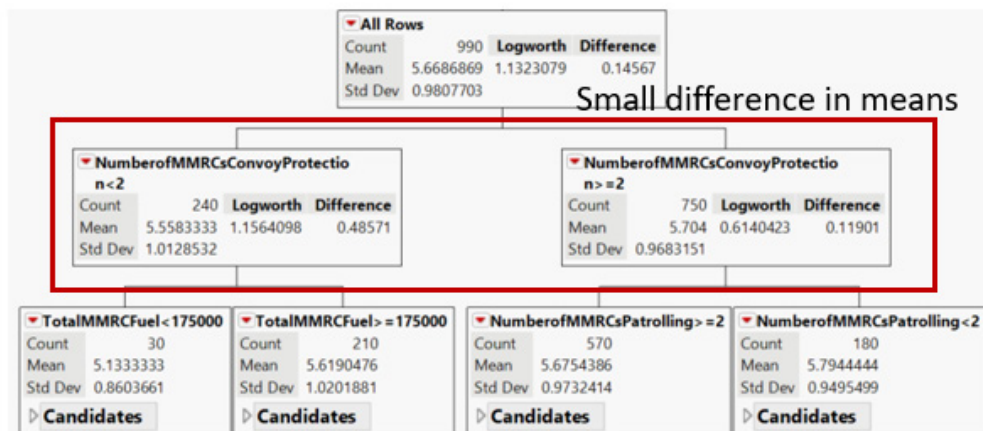
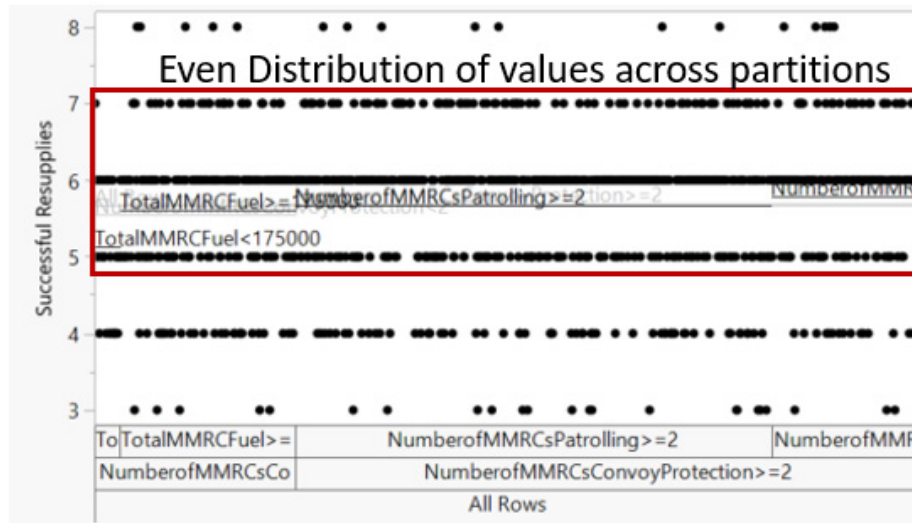


Figure 22. Partition Tree for Successful Resupply

All splits in this partition tree were done optimally, showing which factors and which specific values provided the greatest difference in the results. The first split was on the number of MMRCs in convoy protection. This and the generally flat appearance of the plot further supports the regression analysis conducted showing that the number of convoy protection MMRCs is the only significant factor outside of factor interactions. When there were two or three MMRCs in convoy protection, the average of successful resupplies was at 5.70 compared to cases with only one MMRC which had an average of 5.56 successful resupplies. Further optimal splits were done on each of these nodes. The

splits show that if there is only one MMRC in convoy protection, the next factor to have the maximum impact on results was the total fuel capacity for the MMRCs. If the fuel capacity was at 1750 gallons or greater, the successful resupplies were at an average of 5.62 compared to if less than 1750 gallons, where the average was at 5.13. If the convoy protection had two or three MMRCs, the next factor that had the biggest impact on results was the number of MMRCs patrolling. If there was only one MMRC patrolling, the number of successful resupplies was at 5.79, compared to if there were two or three where the average was at 5.67. While this difference is very minimal, it may suggest that focusing on protecting the supply vessels instead of prioritizing conducting ISR may contribute to more successful resupplies.

The analysis continued to suggest that having more MMRCs in convoy protection to help ward off adversaries employing intimidating tactics on the supply vessels deemed most significant. This was also shown by the fact that having higher numbers of MMRCs in different groups such as the patrolling groups negatively impacted the results. The partition tree was also effective in showing that having a greater fuel capacity for the MMRCs had an impact on the results as they had to refuel less and were able to continue defending the supply vessels against the adversaries. However, because the differences between the means for these factors were so small, it appears that for the resupply mission in particular these factors don't have a very large impact on the outcome despite being significant. The included graph visually shows this lack of overall impact, as both low and high MOE result values are spread evenly across all of the partitioned areas, with no one partition favoring higher values overall.

2. Adversary Detection MOE

To collect results for the number of times an adversary was identified by an MMRC, the python script parsed through the multi-detection output file. At every step of the run, if an MMRC identified an agent from the adversarial squad, an identification was accounted for. The results for all 33 design points ranged from an average 2620 to 14380 adversarial identifications. This vast range can be attributed both to the random nature of the simulation and the wide number of factors that have an impact on the outcome of the

MOE. To prove this claim, a regression analysis was conducted on this data. The coefficients table from the regression analysis is shown in Table 9.

Table 9. Coefficients Table for Adversarial Detections in Competition

Term	Coef	P-Value
Constant	-15273	0.000
MMRCSensorClassificationRange	0.2597	0.000
MMRCSensorApertureArc	279.4	0.000
NumberofMMRCsForwardScouting	946	0.000
NumberofMMRCsPatrolling	927	0.000
NumberofMMRCsConvoyProtection	1033	0.000
TotalMMRCFuel	0.00966	0.000
RedDeterrence	-8.38	0.388

As stated before, the most important statistic to note is the p-value. From this table, every factor in this table is less than 0.05 except for red deterrence. This proves that we can reject the null hypothesis and assume that every factor in fact did have a significant impact on the results, except for adversarial deterrence. Like the resupplies MOE, the insignificance of the red deterrence suggests that potential changes in adversarial tactics should not have a major impact on the number of adversary identifications. To see if the data was a good fit to the regression model, the R-squared statistic was investigated, as can be seen in Table 10. The adjusted R-squared statistic was 93.21%. This high value suggests that the data did have a good fit to the regression model. This explains why the changes in the independent variables caused a lot of variation in the dependent variables.

Table 10. R-Squared Analysis for Adversarial Detections in Competition

S	R-sq	R-sq(adj)	R-sq(pred)
813.000	94.70%	93.21%	90.49%

To help further clarify this analysis, it is important to investigate which combination of factors had the strongest impact on the results. The pareto chart, created from a factorial regression, can be seen in Figure 23.

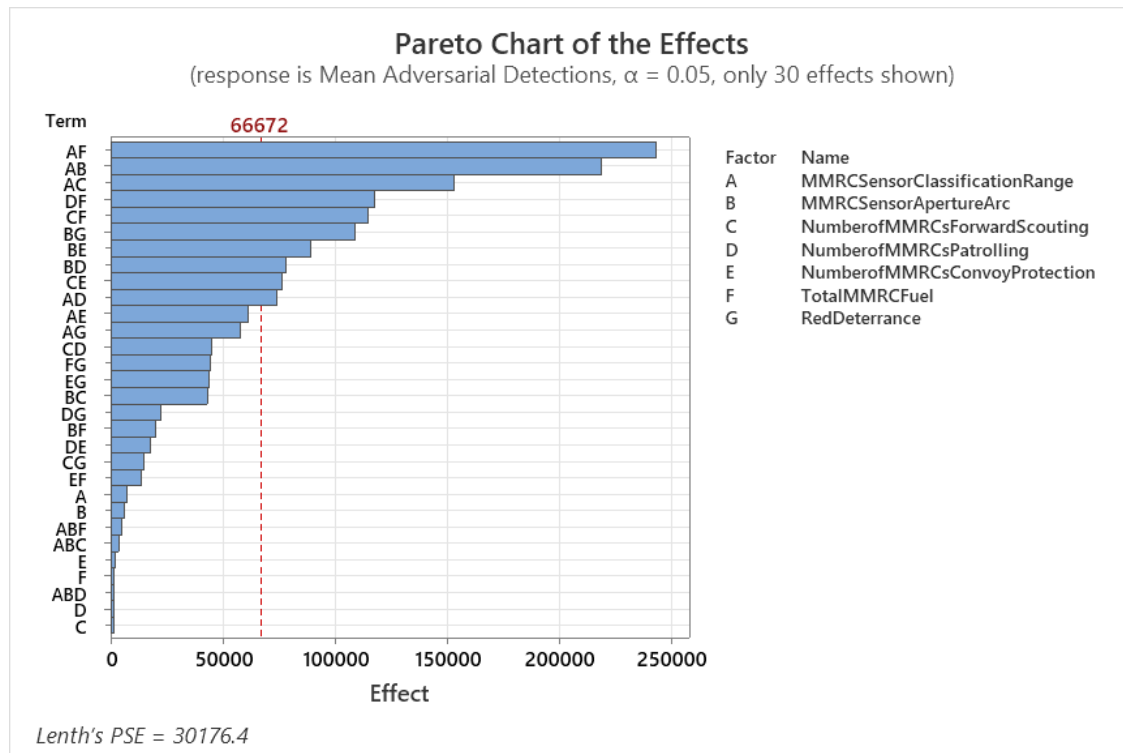


Figure 23. Pareto Chart for Adversarial Detections in Competition

The pareto chart shows that the MMRC sensor classification range is involved in the top three most impactful factor interactions. The top interaction being the with total fuel for the MMRCs, the second being with the sensor aperture arc, and the third combining with the number of MMRCs in forward scouting. This trend of interactions suggests that radar and sensor characteristics along with the number of MMRCs in each scouting area proves most beneficial when needing to increase the detections of adversaries.

To conduct more in-depth analysis, a partition tree was created to help pinpoint more significant factors and what specific values can be most influential in increasing adversary detections. The partition tree can be seen in Figure 24.

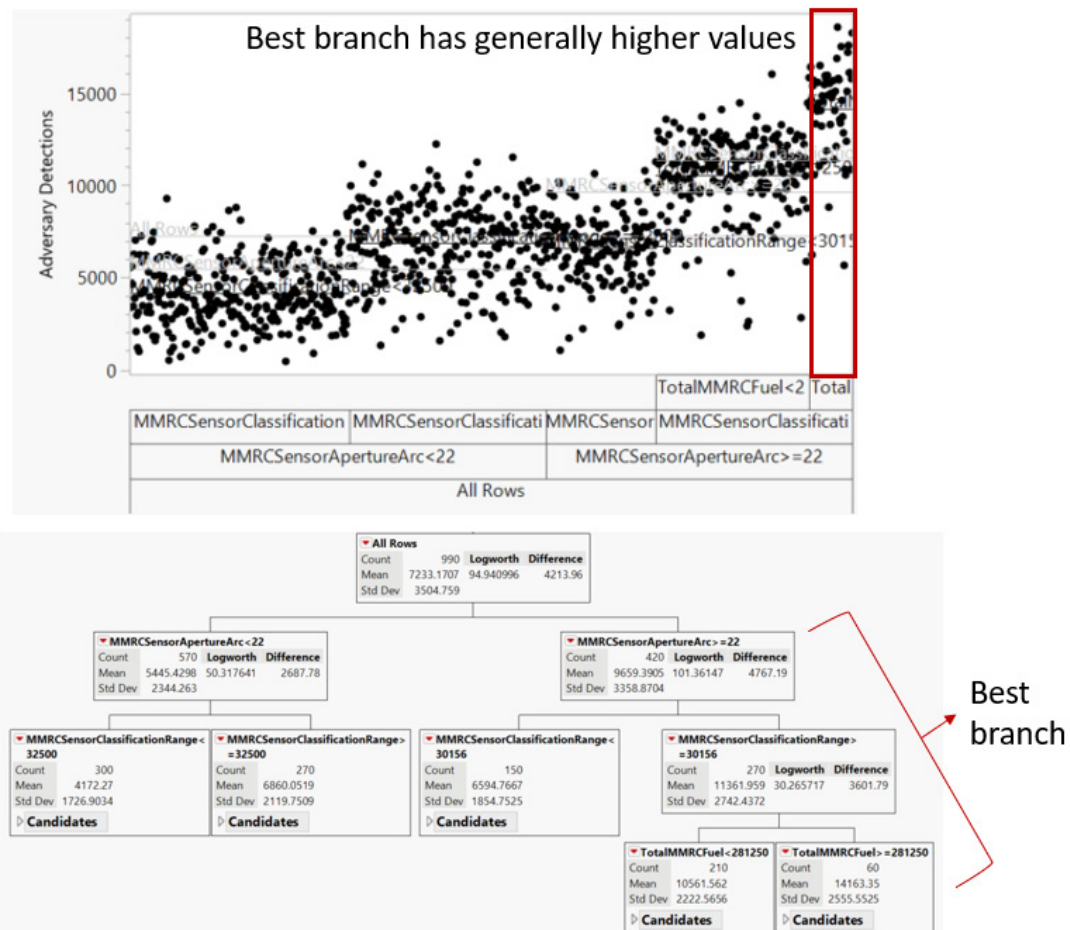


Figure 24. Partition Tree for Adversarial Detections in Competition

Since almost every factor was significant for this MOE, the team focused the partition tree on conducting optimal splits to show the top three most important factors and their impact. The first split was the MMRC sensor aperture arc at 22 degrees, where having a sensor aperture arc of at least 22 degrees raises the average detections by around 4213.96 detections compared to having an arc of less than 22 degrees. Another optimal

split was done on the sensor aperture arc nodes, resulting in the MMRC sensor classification range to be the next significantly impactful factor at specific values. If the sensor aperture arc is less than 22 degrees, having a sensor classification range of at least 32500 meters increases average adversary detections by 2687.78 compared to having a sensor classification range less than 32500 meters. If the sensor aperture arc is 22 degrees or greater, you can get more detections with a smaller sensor classification range. With a 30156 meter or greater sensor classification range there are 11361.96 detections on average, compared to 6594.77 detections at any range below that.

To further analyze any which design characteristics would maximize adversary detections, one more split was optimally done on the ‘best’ branch of the tree from where the sensor classification range was greater than or equal to 30156 meters. This split on the MMRC fuel factor, at the value of 281250, which is a value used in MANA that translates to approximately 2812.5 gallons for the fuel capacity. If the MMRC had a fuel capacity of 2812.5 gallons or greater, the average detections were around 14163.35, compared to 10561.56 detections if the fuel capacity was below this amount. The partition tree overall shows that to maximize detections, the three most important factors are sensor aperture arc, sensor classification range, and total MMRC fuel. This is visually shown in the graph, which shows that the highest values for the MOE were concentrated within that combination of factors.

From the entire analysis on adversary detections, it is beneficial to have strong sensors on the MMRCs, with large sensor aperture arcs and long-distance sensor classification ranges. Additionally, having more fuel available on the MMRC allows them to stay out longer in the LOA and increase the number of adversary detections that are made. While regression analysis showed that every factor besides red deterrence was significant, further analysis showed that the specific impact of these three factors on the number of detections made. The analysis also showed that there is room for trade-offs to maximize effectiveness, as shown in the partition tree that having a higher aperture arc allows for the classification range to be a smaller range but still maximizes detections.

3. Adversary Pursuit MOE

The adversary pursuit MOE is the percentage of time during a run that an MMRC spends in an engagement state with an adversary. This was calculated by measuring the number of time-steps each MMRC spent in an enemy contact state, which was multiplied by the amount of time each time step represents. This total time was then divided by the total time of the run multiplied by the number of MMRCs in the scenario to represent the total time available to all MMRCs.

The results for each design point ranged from 17.64% mean engagement time to 76.14% mean engagement time. The difference in percentages is attributed both to the random nature of the simulation and to the fact that most of the factors had a significant impact on the results. The coefficients table produced from the regression analysis can be seen in Table 11.

Table 11. Coefficients Table for Adversarial Pursuit

Term	Coef	P-Value
Constant	-66.4	0.000
MMRCSensorClassificationRange	0.000948	0.000
MMRCSensorApertureArc	0.897	0.002
NumberofMMRCsForwardScouting	4.93	0.024
NumberofMMRCsPatrolling	6.86	0.003
NumberofMMRCsConvoyProtection	4.96	0.024
TotalMMRCFuel	0.000063	0.019
RedDeterrence	-0.1233	0.223

Every factor except for the red deterrence was below the 0.05 p-value threshold, which suggests that our team will reject the null hypothesis and that every factor besides the red deterrence will have a significant impact on the time the MMRCs are spent engaged with the adversary. Like the other MOEs, this shows that potential changes in adversarial tactics should not have a significant impact to these results. To see the level of goodness of fit for the data, the adjusted r-squared value from the regression analysis is shown in Table 12.

Table 12. R-Squared Analysis for Adversarial Pursuit

S	R-sq	R-sq(adj)	R-sq(pred)
8.40588	74.29%	67.09%	53.16%

The value of the adjusted r-squared statistic is 67.09%, which suggests that the data fit the regression model fairly well. While it could be better, there is still important information that could be obtained from this analysis. The changes in the independent variables would cause changes to the dependent variables. To further investigate which interaction of factors will contribute more to the results, a pareto chart of the effects from a factorial regression was created and can be seen in Figure 25.

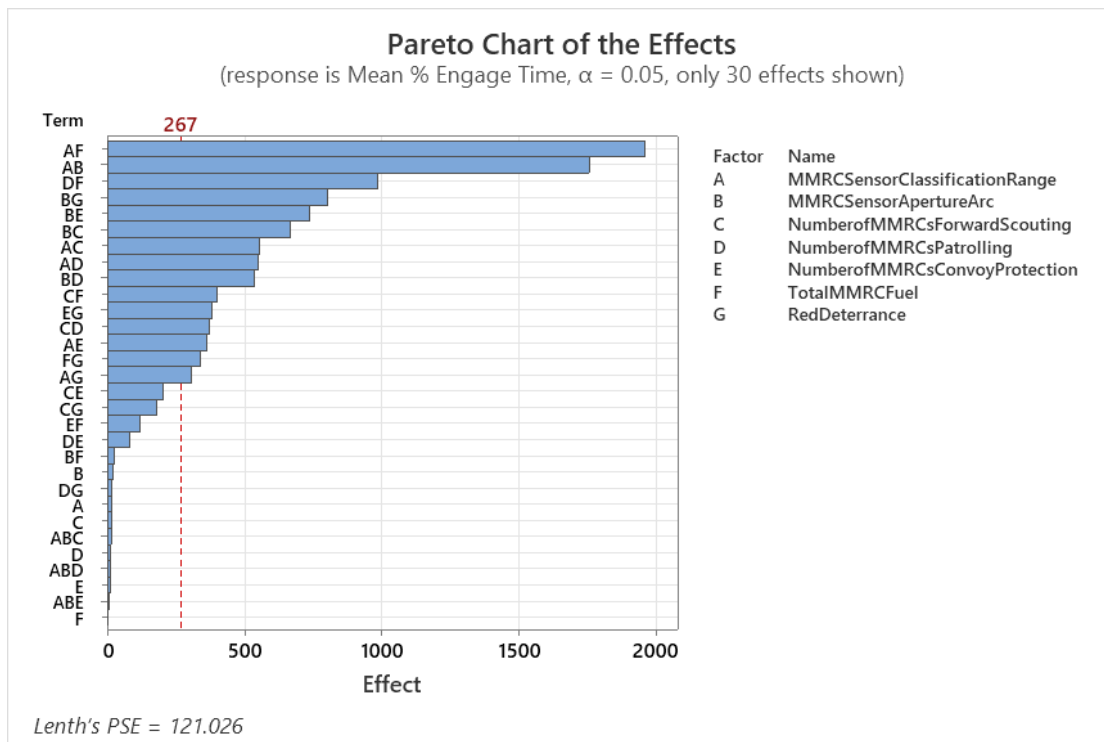


Figure 25. Pareto Chart for Adversarial Pursuit

The greatest impact that was shown on the results was the MMRC sensor classification range and the total fuel in the MMRCs. The second was the sensor classification range and the sensor aperture arc, and the third most significant interaction

is the number of MMRCs patrolling and the total fuel of the MMRCs. This suggests that focusing on a good radar system would prove to provide the best return on investment, while also ensuring that the MMRC's fuel capacity is greater so that they may be in the field and operationally available for a longer period. To support these claims, a partition tree was created to further help identify what specific values for these factors can be most influential in the amount of time spent in engaging with the adversaries. The partition tree can be seen in Figure 26.

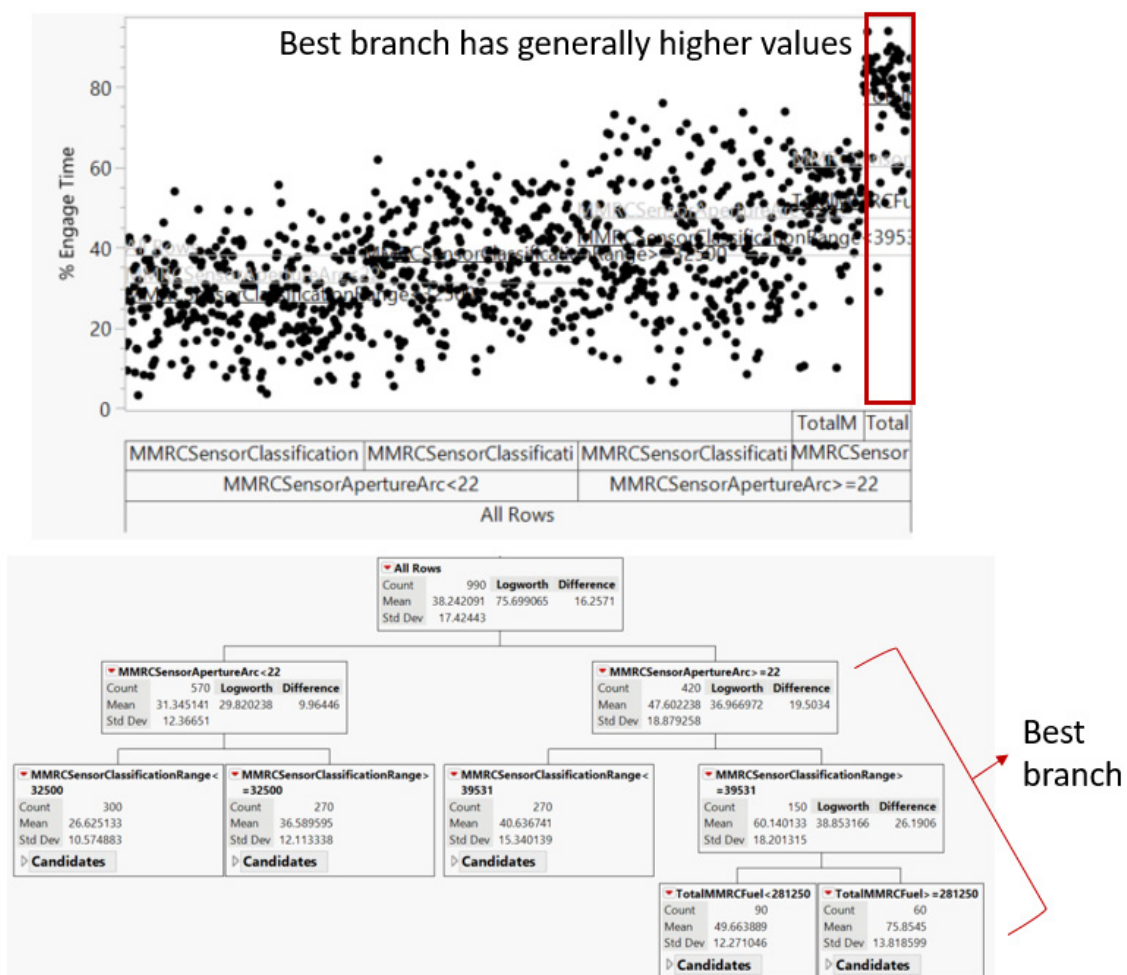


Figure 26. Partition Tree for Adversary Pursuit

As seen from the partition tree, the first optimal split done resulted in the sensor aperture arc being at a value of 22 degrees, the same value seen for the adversary detections MOE. With a sensor aperture arc of at least 22 degrees, the engagement time spent in the simulation for MMRCs was around 47.60%, compared to 31.35% when the aperture arc was less than 22 degrees. Optimal splits from this point continued to narrow down on aperture arc, so to continue the analysis the team chose to split on specific factors based on those seen as most impactful in the pareto chart of interactions. The second split off the aperture arc was chosen to be the sensor classification range. When the aperture arc is less than 22 degrees, the optimal split for the sensor classification range is at a value of 32500 meters. If equal or greater to this value, engagement time was at 36.59% compared to 26.63% at lesser values.

When the aperture arc is 22 degrees or greater, the split for the classification range was at 39531 meters. If equal to or greater, engagement time was at 60.14% compared to 40.64% at lesser values. Focusing on this ‘best’ branch of the tree, another split was conducted using the total MMRC fuel factor. The value was optimally split at a value that equates to 2812.50 gallons fuel capacity, same as seen in the adversary detection MOE. If equal or greater than this value, the engagement time was at 75.86% compared to 49.66% at lesser values. This best branch idea is visually shown in the graph, which shows that the highest values for the MOE were concentrated within that combination of factors. This high percentage of time spent in adversarial pursuit suggests successful decoy techniques, prolonging the time the adversary is distracted from their original intentions. This suggests that a focus on maximizing radar and sensor capabilities, as well as maximizing the fuel capacity for an MMRC can help contribute to the success of deception missions.

B. CONFLICT DOE RESULTS

While the scenario was different, the analysis process for the conflict DOE was conducted similarly to the competition DOE. For each of the 990 runs conducted, the results collected consisted of the number of adversary detections, the percentage of successful TRAP missions conducted and the percentage of MMRCs that survived

throughout the scenario timeline. The chosen DoE factors were compared against each MOE to determine the most important factors to consider when in conflict. As with competition, our null hypothesis is that there is no significant relationship between any of the factors and the MOE value, while our alternative hypothesis is that a significant relationship exists between any factor and the MOE value. The analysis was conducted with a 95% confidence interval, inferring a key p-value of 0.05. If any factor has a p-value of 0.05 or less, then the null hypothesis is to be rejected and the alternative hypothesis is accepted.

1. Adversary Detection MOE

The same method to count the number of adversary detections in the competition analysis was done for the conflict DoE results. The results for all 33 design points ranged from an average 60 to 1113 adversarial identifications, at levels much lower than seen in the competition scenario. This can likely be attributed to the MMRC's more avoidant behavior, to avoid active conflict. Like the competition analysis, the vast range in values can be attributed both to the random nature of the simulation and the wide number of factors that have an impact on the outcome of the MOE. To prove this claim, a regression analysis was conducted on this data. The coefficients table from the regression analysis is shown in Table 13.

Table 13. Coefficients Table for Adversarial Detections in Conflict

Term	Coef	P-Value
Constant	-1262	0.000
MMRCSensorClassificationRange	0.03020	0.000
MMRCSensorApertureArc	17.96	0.000
NumberofMMRCs	86.1	0.008
MMRCFiringRange	0.0338	0.488
MMRCHTK	46.5	0.132
AdversaryFiringRange	-0.00218	0.764

Investigating the p-values, the factors that are below 0.05 are the MMRC sensor classification range, the sensor aperture arc, and the number of MMRCs in the patrol group. This suggests we may reject the null hypothesis as these factors had a significant impact on the MOE value. The firing ranges and the MMRC's hits-to-kill did not play as a significant role in this analysis. This supports the logic that to increase adversary detections, increasing sensor capabilities and the amount of MMRCs present must be the focus. Following the same techniques as the competition analysis, the R-squared statistic was investigated, as can be seen in Table 14. The adjusted R-squared statistic was 82.10%. This fairly high value suggests that the data did have a relatively good fit to the regression model. This explains why the changes in the independent variables caused a lot of variation in the dependent variables.

Table 14. R-Squared Analysis for Adversarial Detections in Conflict

S	R-sq	R-sq(adj)	R-sq(pred)
122.725	85.46%	82.10%	75.77%

To continue investigating if these claims are valid and analyzing the results, the pareto chart was investigated to understand which combination of factors had the strongest impact on the results, if any. The pareto chart, created from a factorial regression, can be seen in Figure 27.

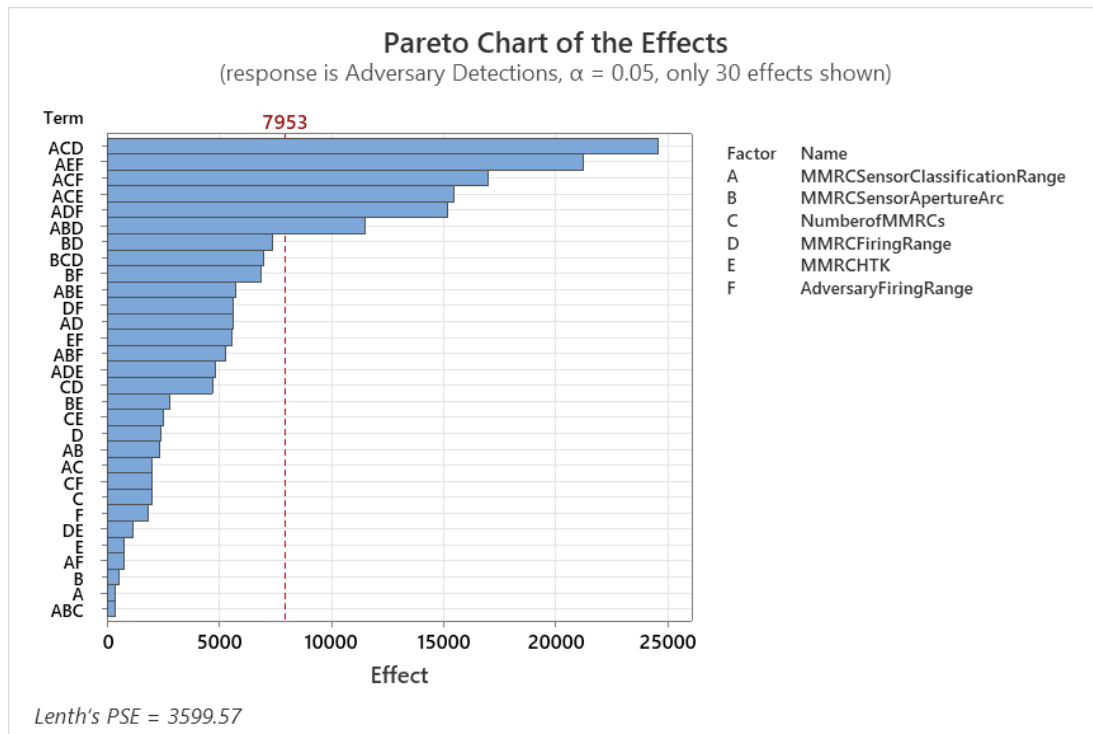


Figure 27. Pareto Chart for Adversarial Detections in Conflict

The pareto chart shows that the MMRC sensor classification range is involved in the top six most impactful factor interactions. This supports the claim that this is a significant factor and had a major impact on the results. The top combination shown in the chart is the sensor classification range, number of MMRCs and the MMRC firing range. Three of the top 4 interactions include the number of MMRCs, further proving that this factor has a major impact on the results. The trend of interactions suggests that the MMRC firing range, the MMRC hits-to-kill, and the adversary firing range do become impactful when combined with the sensor classification range and number of MMRCs, but not when considered on their own. After this analysis was conducted, a partition tree was created to understand what specific values of certain factors can be the most beneficial in increasing adversary detections. The partition tree can be seen in Figure 28.

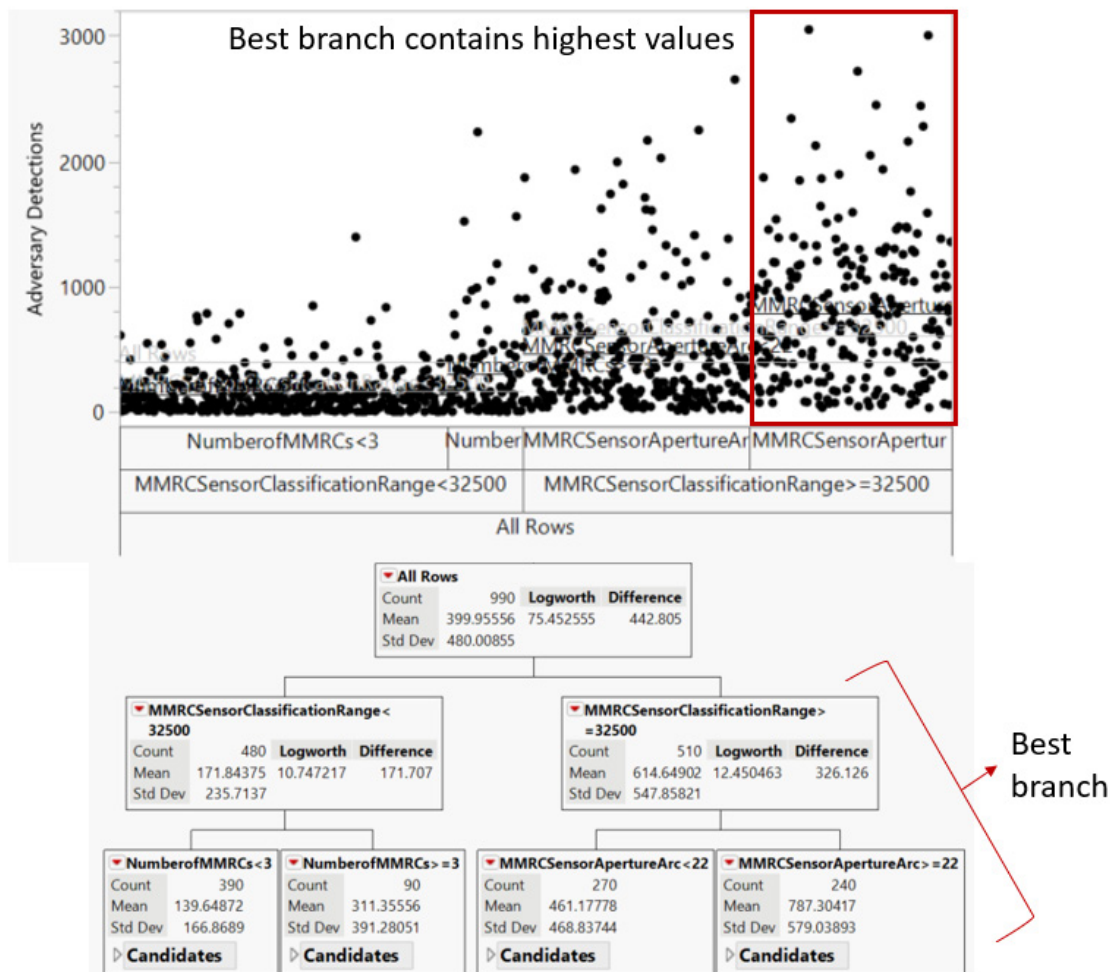


Figure 28. Partition Tree for Adversarial Detections in Conflict

All splits in this partition tree were done optimally to see the best factor and the best values for splitting the data into subsets. The first split is done on the MMRC sensor classification range at 32500 meters. When the classification range was 32500 meters or greater, the average adversarial detections was 614.65 detections, compared to 171.84 detections below that value. With the sensor classification range being less than 32500 meters, the next optimal split was with the number of MMRCs with the datasets being split at 3. If there were 3 or more MMRCs, the detections were at an average of 311.36. If there were less than 3 MMRCs, the average fell to 139.65 detections. This difference of 171.71 average detections suggests that if sensor capabilities are unable to be up to par

with 32500 meters, the next important factor to consider is having more MMRCs to be able to make the detections necessary. However, if the sensor classification is 32500 meters or more, the partition tree shows the next optimal split would be to focus on the sensor aperture arc. If the sensor aperture arc was at 22 degrees or more, the average adversarial detections was at 787.30 and was at 461.18 average detections if less than 22 degrees. This difference together with the difference for sensor classification range show the importance of focusing on sensor values to improve detection rates. This is shown visually in the graph, where the highest detection values are located within the combination of high aperture arc and sensor classification range.

The regression analysis, factorial regression, and the partition tree all point to the most significant factors for higher numbers of adversary detections being sensor capabilities and the total number of MMRCs. The higher r-squared statistic does suggest that variability is accounted for, and the independent variables do have a strong relationship with the dependent variable.

2. TRAP Support MOE

In the conflict scenario, the MMRCs are sent out to conduct a rescue operation if an F-18 combat plane is downed during combat. To measure this, the python script compared the number of injured planes to the number that had been successfully rescued and calculated a percentage of successful rescue missions. For the three repetitions in which no planes were injured, the TRAP value was left blank and was not factored into the averages or partition trees. The results ranged from 85% to 100% of TRAP missions resulting in a successful rescue operation. The goal is to have the highest percentage possible for this MOE, so it is especially important to note which factors have a significant relationship with the MOE value. A regression analysis was conducted, and the coefficients table can be seen in Table 15.

Table 15. Coefficients Table for TRAP Support

Term	Coef	P-Value
Constant	91.16	0.000
MMRCSensorClassificationRange	0.000046	0.534
MMRCSensorApertureArc	0.0401	0.666
NumberofMMRCs	1.818	0.025
MMRCFiringRange	-0.00062	0.618
MMRCHTK	1.398	0.078
AdversaryFiringRange	-0.000129	0.487

From the p-values, the only factor to have a value less than 0.05 is the number of MMRCs in the patrol group. This allows us to reject the null hypothesis since this factor does indeed have a significant impact on the results. While the MMRC's hits-to-kill does not meet the threshold, it is important to note that its low p-value does suggest that the MMRC's survivability plays a role in these results as the MMRC does need to be fully operational to complete this mission. Also from the regression analysis, the adjusted R-squared value is 13.87%. The model summary with the R-squared statistics is shown in Table 16. This leads to believe that the data did not fit the regression model very well and there is quite unexplained variability in the results based on the changes in the factors. This may be confirmed by their only being one variable, the number of MMRCs in the patrol group, that proved to be statistically significant.

Table 16. R-Squared Analysis for TRAP Support

S	R-sq	R-sq(adj)	R-sq(pred)
3.12153	30.02%	13.87%	0.00%

Like the other MOE analyses, the pareto chart of the effects from a factorial regression analysis was created to show the combination of factors that had a significant impact on the results. The pareto chart can be seen in Figure 29.

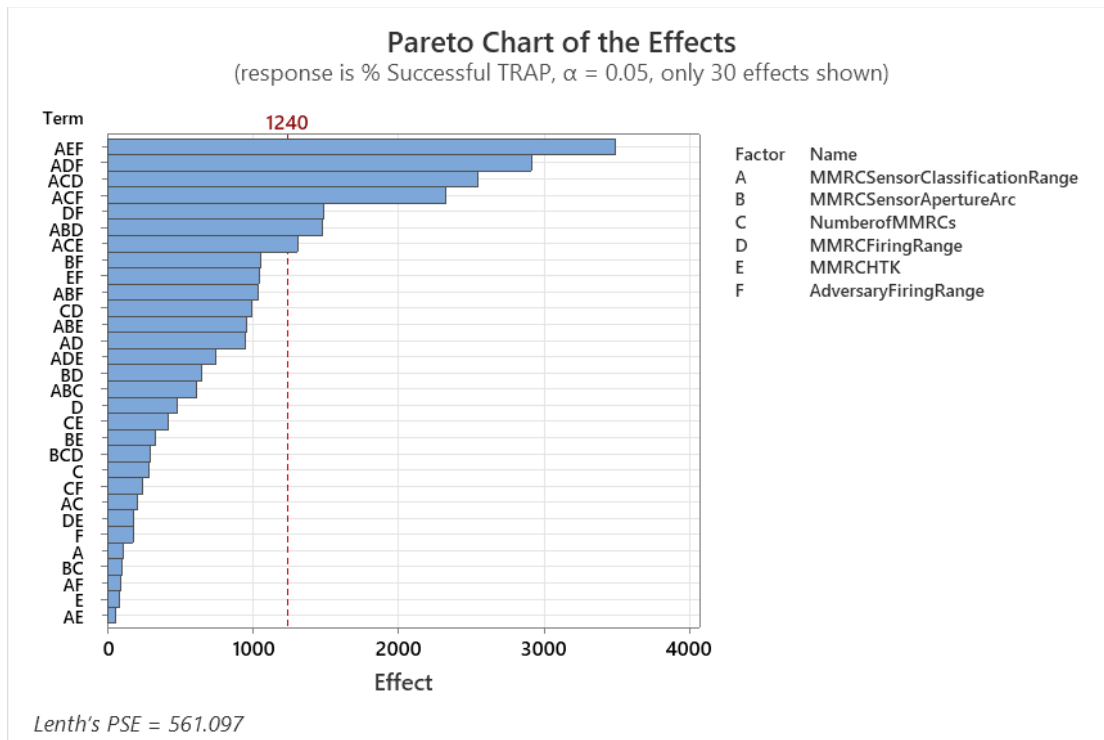


Figure 29. Pareto Chart for Successful TRAP

The pareto chart shows that the sensor classification range, the MMRC hits-to-kill, and the adversary firing range when combined had the greatest effect on the results. The top four combination terms also include the MMRC firing range and the number of MMRCs in the patrol group. These various combinations overall suggest that due to the small difference in results and higher unexplained variability, many different factors can become significant when interacting with one another in the simulation. The chart overall suggests that the sensor and weaponry capabilities, the MMRC's hit-to-kill, and the number of MMRCs should be the focus to increase the chance of a successful TRAP mission. This is a lot of factors to consider, making further analysis important so that a clearer focus can be suggested.

The analysis of this MOE has shown that the number of MMRCs is the only significant factor. The pareto chart has also shown several combinations that have a great effect on the results. A partition tree will aid in focusing on significant factors as well as

provide the values to provide a stronger suggestion. The partition tree can be seen in Figure 30.

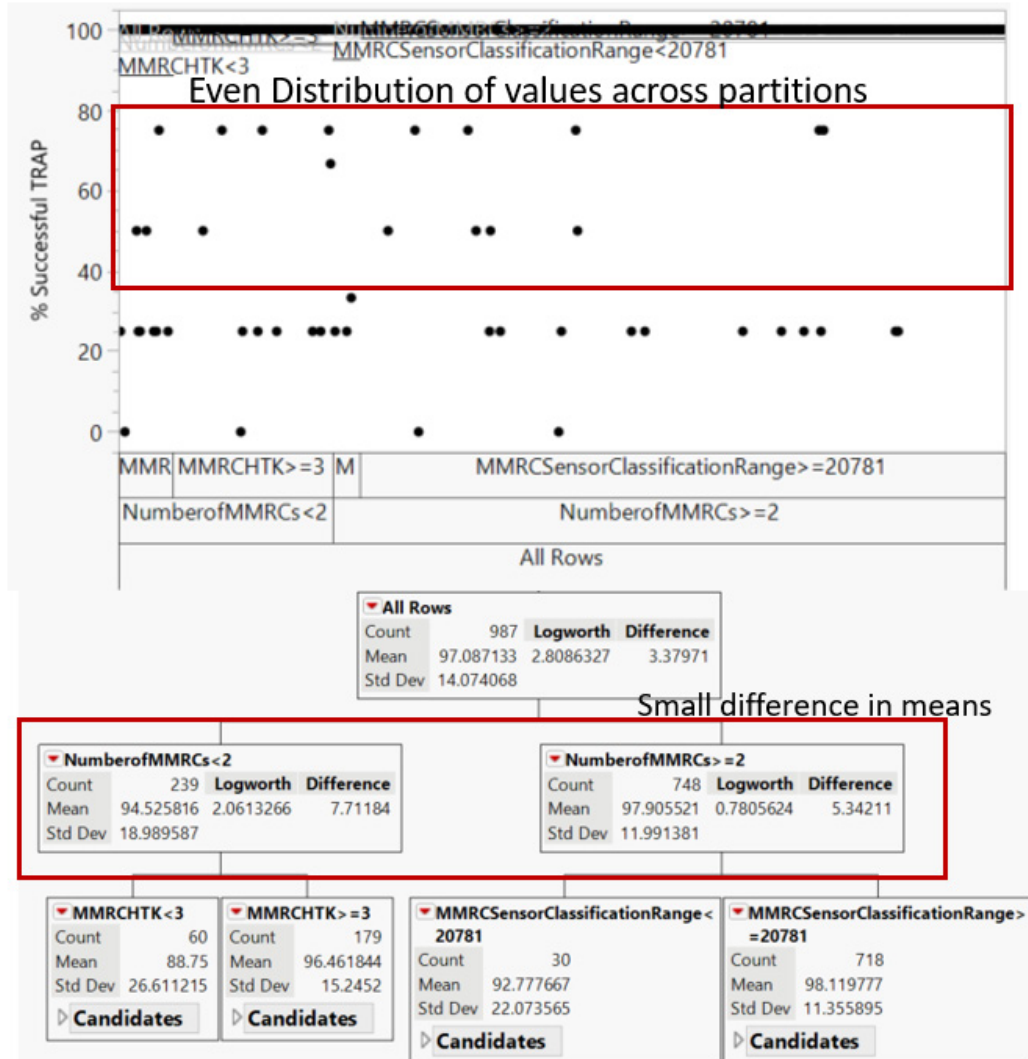


Figure 30. Partition Tree for Successful TRAP

This partition tree was conducted on 987 runs instead of the usual 990 due to the exclusion of the three runs in which no planes were downed. All splits were made optimally, with the first split done on the number of MMRCs. If there were 2 or more MMRCs present in the simulation, 97.91% of the TRAP missions were successful. If

there was only 1 MMRC present, the percentage of successful TRAP missions was at 94.53%. While this is not a significant difference, does suggest that the number of MMRCs may have some small impact on achieving a higher percentage of successful TRAP missions. If there was only 1 MMRC present, the next optimal split was shown to be the number of hits an MMRC could receive before being 'killed'. If the sole MMRC had a hits-to-kill of 3 or higher, 96.46% of the TRAP missions were successful. If it took less than 3 shots to kill the MMRC, only 88.75% of the TRAP missions were successful. This is not a very significant difference but could show the importance of durability to the MMRC being able to complete a mission. If there are 2 or more MMRCs, the next important factor was the MMRC sensor classification range at 20781 meters. If the classification range was 20781 meters or greater, the percentage of successful TRAP missions was 98.12%, compared to 92.78% successful TRAP missions conducted if the sensor classification range was less than 20781 meters. Again, while this is not a significant difference, the focus on strong sensor capabilities is a frequent theme throughout this analysis.

The regression analysis suggested that the number of MMRCs to be the only significant factor. It also showed, along with the pareto chart and the partition tree, that the MMRC hits-to-kill, while not statistically significant, can have an impact on the results. The pareto chart and the partition tree also suggested that sensor capabilities are also impactful on the results. The low r-squared statistic and partition tree plot show that there is not a strong relationship between the factors and the results, and that there is a lot of variability left unexplained. Also, the small difference between the lowest result at 85% and the highest result at 100% suggests that overall, the factors impact on the results is minimal. The included graph visually shows this lack of overall impact, as both low and high MOE result values are spread evenly across all of the partitioned areas, with no one partition favoring higher values overall.

3. MMRC Survivability MOE

In the conflict scenario, the MMRC is susceptible to attacks from the adversary. This makes the MMRCs survivability a crucial factor to consider, to ensure the mission

can be accomplished successfully and protect the crew. Survivability was measured in the python script by calculating the total percentage of MMRCs that were not in the ‘Dead’ state at the end of the simulation. The results from all the design points range from an average of 39.26% to 80.74% survivability rate. This rather large difference suggests that there are several factors that have a significant relationship with the results. The coefficients table from a regression analysis can be seen in Table 17.

Table 17. Coefficients Table for MMRC Survivability

Term	Coef	P-Value
Constant	45.0	0.000
MMRCSensorClassificationRange	0.000302	0.021
MMRCSensorApertureArc	0.097	0.532
NumberofMMRCs	0.31	0.812
MMRCFiringRange	0.00231	0.268
MMRCHTK	9.65	0.000
AdversaryFiringRange	-0.001318	0.000

The factors that are deemed significant by p-value of less than 0.05 are the MMRC sensor classification range, the MMRC hits-to-kill, and the adversary firing range. With this, the null hypothesis may be rejected. The capabilities of the adversary’s weaponry as well as the MMRC’s hits-to-kill prove to be a focus area of concern when needing to have a high MMRC survivability. From the regression analysis, the R-squared statistic was 71.96%. The model summary with the R-squared statistics is shown in Table 18. This moderately high R-squared value leads to believe that the data did fit the regression model somewhat well. This can be attributed to the fact that there were significant factors in the results and more variability can be explained.

Table 18. R-Squared Analysis for MMRC Survivability

S	R-sq	R-sq(adj)	R-sq(pred)
5.22736	77.22%	71.96%	64.43%

To analyze which combination of factors had a significant effect on the results for MMRC survivability, the pareto chart from a factorial regression analysis can be seen in Figure 31.

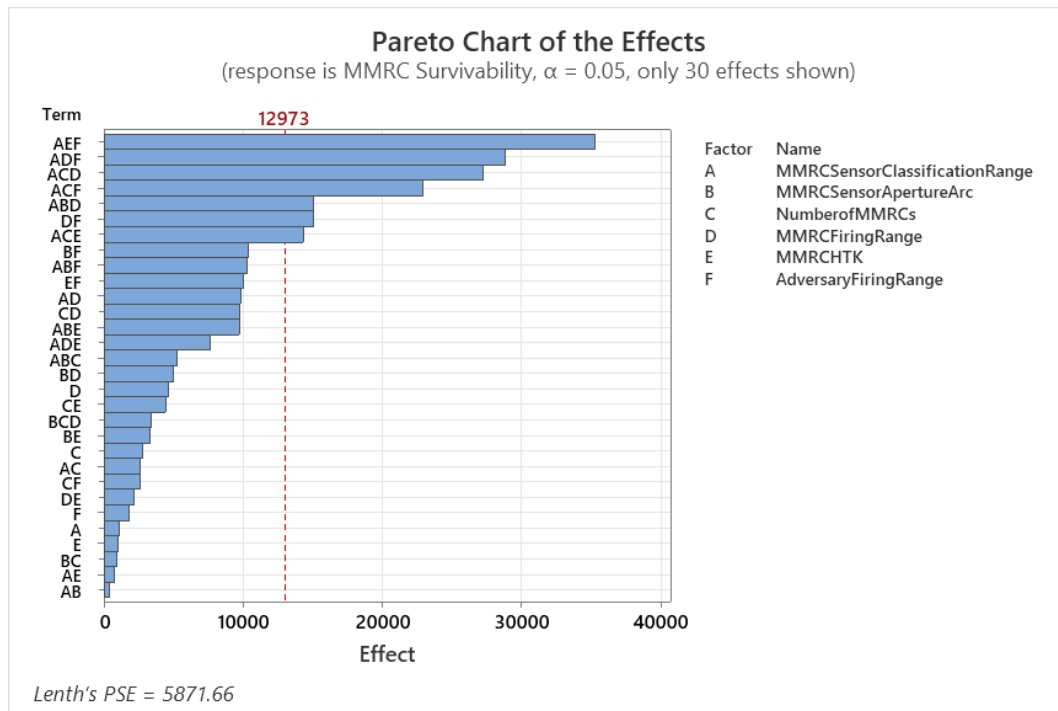


Figure 31. Pareto Chart for MMRC Survivability

The pareto chart shows that the combination of factors that had the biggest effect on the results were the MMRC sensor classification range, the MMRC hits-to-kill, and the adversary firing range. All these factors alone proved to be significant from the regression analysis, and combined they also play a major role in the determination of the MMRCs survivability. The next combination of factors that influenced the results was the sensor classification range, the adversary firing range, and the MMRC firing range. This trend continues to prove that to have high MMRC survivability, it must have strong sustainability and weaponry, as well as understanding the adversary's position and weapon capabilities. With a solid trend of understanding the significant factors for this MOE, a partition tree was created to determine the specific values of the factors that will

prove most beneficial in increasing the MMRC's survivability. This partition tree can be seen in Figure 32.

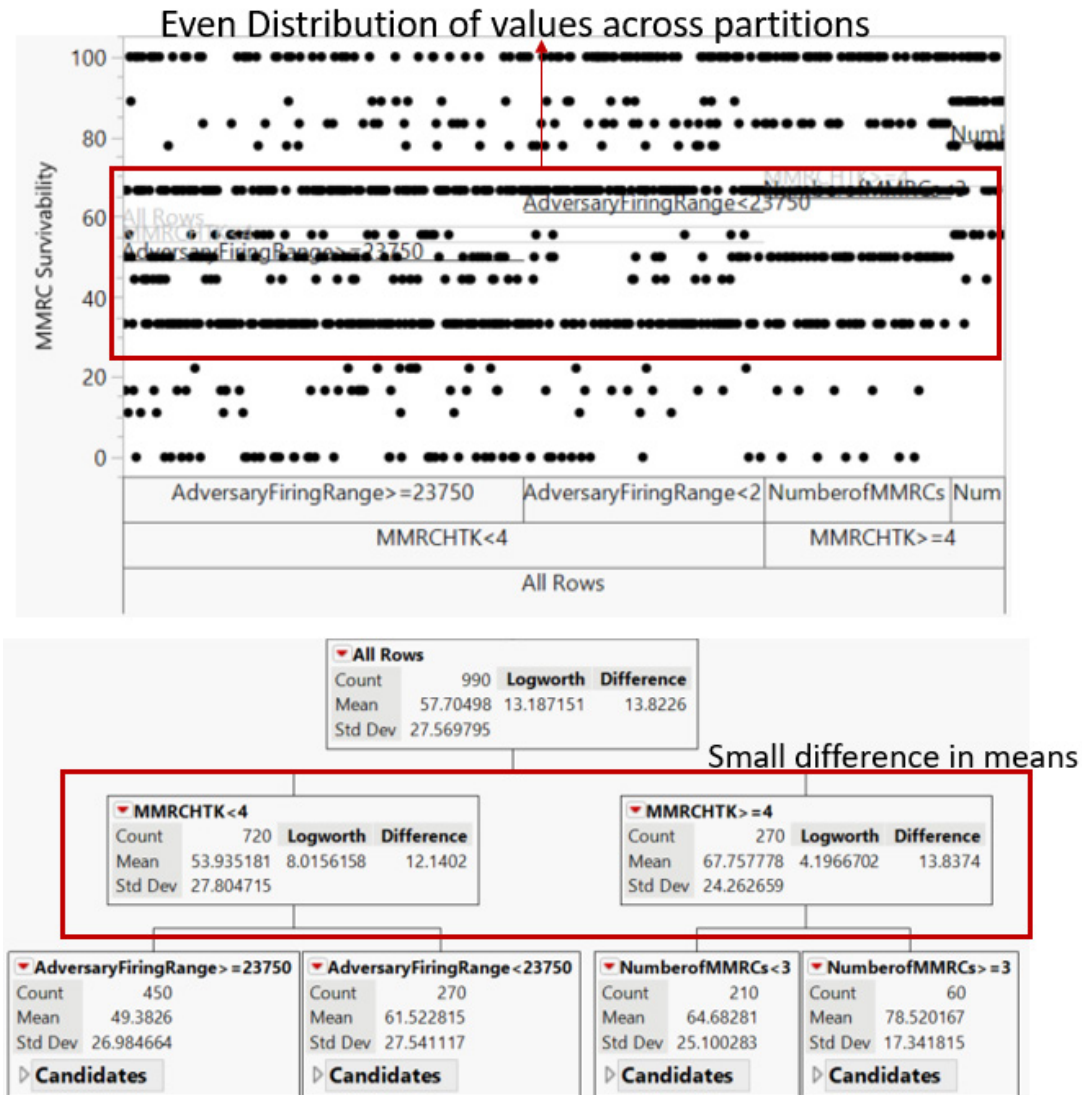


Figure 32. Partition Tree for MMRC Survivability

Like the other partition trees, all splits for this partition tree were done optimally to show the factor and the value that would be best for splitting the data into subsets. The first split is on the MMRC's hits-to-kill. If the hits-to-kill was at 4 shots or more, the percentage of MMRCs to not be killed at the end of the simulation was at 67.76%,

compared to 53.94% at lower values. Based on the standard deviation this does not seem to be a significant difference, so while it does not have a major impact it does suggest that a durable MMRC could provide benefits for survivability. If the MMRC's hits-to-kill was less than 4, the next split was in the adversary's firing range with the split value being 23750 meters. If the adversary's firing range was less than 23750 meters, the survival rate for the MMRCs was at an average of 61.53%, while with greater weapon capabilities the average survivability for the MMRCs was at 49.38%. While not significantly different this suggests the more capable the adversary is, the more important it is for the MMRCs to have improved durability to survive attack. When the MMRC hits-to-kill was 4 or greater, the next split was on the number of MMRCs present in each squad throughout the simulation. If there were 3 or more the MMRC survivability rate was at 78.52%, while below that the survivability rate dropped to 64.68%. Again, this does not show a significant difference but suggests that to a small extent adding more MMRCs to each squad could help provide greater survivability through strength in numbers. The included graph visually shows this lack of overall impact, as both low and high MOE result values are spread evenly across all the partitioned areas, with no one partition favoring higher values overall.

The regression analysis showed that the significant factors were MMRC hits-to-kill, adversary's firing range, and the MMRC sensor classification range. This was shown by the pareto chart as well, as the top combination to have the greatest effect on these results was these three factors. While the partition tree had a low r-squared value and no very significant differences in means, the hits-to-kill and the adversary firing range factors did appear in splits as potential small increases in survivability. The tree also suggested that number of MMRCs in each squad could have some impact when the hits to kill an MMRC were greater. This was also shown in the pareto chart where the number of MMRCs factor was shown in two of the top four combinations. With the r-squared statistic in the regression analysis showing a fairly strong relationship between the factors and the results, the trend shows that it is significant to focus on the MMRC's durability, sensor capabilities, the number of MMRCs present while keeping the adversaries weaponry capabilities in mind.

C. CONCLUSIONS OF ANALYSIS

For the competition scenario, the MMRC sensor classification range frequently appeared as one of the most significant factors for the results. This was mixed in with the sensor aperture arc, the total fuel, and the positioning and grouping of the MMRC squads depending on the specific objective of the mission. From this, it is safe to conclude that the most important design factor to be considered is the radar system. If the MMRC can identify and classify adversarial ships quicker, it allows for faster decision making on what tactics need to be done or changed in order to successfully complete the missions of successful resupplies and conducting ISR. There are also benefits to having a greater fuel capacity for the MMRCs to keep them operationally available longer, as well as having them in certain groups of either convoy protection for the successful resupplies or patrolling and forward scouting for conducting ISR. The optimum fuel levels suggested by the partition charts are below the suggested 3000 gals for the proposed MMRC design, so current design should be sufficient in that area. In general, the best results all seem to conclude that having a solid radar system overall contributes to the successful missions and that should be the focus of the MMRC's design parameters.

For the conflict scenario, the MMRC sensor classification range consistently appeared as one of the most significant factors in the results both on its own and in combination with other factors. Other factors that frequently showed to have some impact were the number hits it took to kill an MMRC, the number of MMRCs present in each squad in the simulation, and the adversary's firing range. Like the competition scenario, it proved to be most beneficial when the MMRCs had the capability to identify and classify adversarial ships quicker, allowing for faster decision making on what tactics needed to be done to complete a successful mission. Due to this being a scenario where weaponry was involved, the next important factor seems to be the durability of the MMRC. With the MMRC being able to endure more shots taken, it was able to survive and operate longer to successfully complete more missions. 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. The first non-controllable factor was proven to be significant with the adversary's firing range, specifically for MMRC survivability. To counter this, it could be tied back in to the first three significant factors of sensor classification range, the hits to kill an MMRC, and the number of MMRCs present as this allows for more detections and operable MMRCs being able to communicate and employ defense tactics at a more effective rate.

VII. CONCLUSIONS

A. SUMMARY

This team set out to utilize mission engineering principles to answer the following questions for the employment of MMRC squadrons in both a competition and conflict scenario:

1. 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?
2. What measures of effectiveness (MOEs) best represent the achievement of success in the employment of Ellis-Class MMRCs in an operational scenario?
3. What are the significant design decisions and operational parameters for the Ellis-Class MMRCs that provide the largest impact on the measures of effectiveness in relevant and complex operational scenarios?

After developing an understanding of the system and the two different scenarios outlined, MBSE was utilized to outline the different missions within each scenario and how each element within the system interacts. From this, the team was able to identify three main MOEs 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 partner nation littoral territory.

The MBSE models were used as the basis for developing agent-based simulations of each scenario, to determine what design factors may have a significant impact on the teams chosen MOEs. For each scenario a design of experiments was conducted, with 7

factors altered for competition and 6 factors altered for conflict. Each DOE produced 33 unique design points with 30 replications, for a total of 990 runs of each simulation. The results from these runs were analyzed for each MOE, conducting analysis through regression analysis and partition trees.

While the significant factors varied depending on the MOE and scenario being conducted, some overall themes did emerge from the analysis. In competition, the best results all seem to conclude that having a solid radar system through high sensor classification levels and larger aperture arcs contributed to mission success and could be an important design parameter to focus on. 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’. 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.

B. RECOMMENDATIONS FOR FUTURE WORK

This research project provided a high-level analysis of several of the potential MMRC missions in competition and conflict and competition scenarios, but due to limitations in time and resources was not able to explore all possible missions or scenarios. The team recommends the following areas for future research on this topic:

- Analysis of additional MOE values within the context of the existing competition and conflict simulations
- Simulation of additional functionalities, such as supporting anti-submarine warfare, performing focused collection operations, and coordinating with partner nation forces.
- Modeling the impacts of the UxVs on MMRC squadron mission success.
- Simulations using higher fidelity models to better simulate the impacts of weather and sea state on MMRC squadron performance.

- Simulation of the impacts of counter-measure support from the MMRCs on conflict mission success.

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APPENDIX A. AGENT INPUT IN MANA

A. COMPETITION

The screenshot displays the MANA interface for configuring MMRC agents. The interface is divided into several panels:

- GENERAL:** Side Name: MMRC Squad 1, Flag Icon: 0, No. of Agents: 2, Squad Active: ☒, Default State Icon:
- FUEL TANK:** Initial Fill: 200000, ☐ Agent is Auto-Refueller
- MISCELLANEOUS:** ☒ Terrain Affects Movement (Deselect for aircraft agents.), ☐ Agents Allowed on Rooftops, Sound Fx: ☐ Goal, ☒ Fire, ☒ Die
- EMBASS:** Parent Squad: 0
- INITIAL AGENT ORIENTATION:** Bearing: 0 (degrees), ☒ Towards (x = 0.0000, y = 0.0000, n. miles), ☐ Away From (x = 0.0000, y = 0.0000, n. miles), Initial Scan Direction: ☒ Clockwise, ☐ Anti-clockwise, ☐ Random
- SELF PROTECTION:** No. Hits to Kill: 100, Personal Concealment per Detection Event: 0 %, Armour Thickness: 0 mm
- WAYPOINTS:** Waypoint Radius: 200 metres, Dynamic Waypoint Radius: 1 metres
- EMBASSING BEHAVIOUR:** ☒ Release from Parent Squad, ☒ Release Child Squads, ☐ Embuss Children, Embussing Radius: 1 metres
- ANGULAR MOVEMENT:** Slew Rate: 180 degrees per second, Face Enemy on: ☒ Agent SA, ☐ Squad SA, ☐ Inorg. SA, Face Unknowns on: ☐ Inorg. SA, In absence of enemy: ☐ No Change, ☐ Look in Direction of Movement, ☐ Patrol Mode, ☒ Scan 360 degrees, ☐ Scan Back and Forth, ☐ Scan Towards Direction of Movement, ☐ Patrol Scan Mode, Arc of Scan: 180 degrees, ☐ Respond if shot at, for time = 5 seconds
- Copy Squad, Delete Squad, Save Squad, Load Squad**
- Agent SA:** Enemies: 75, Min App. 0, Max. Inf. 25000, ☐ Combat, All distances are in metres. Enemy Threat 1: 0, Enemy Threat 2: 0, Enemy Threat 3: 0, Ideal Enemy: 0, En. Class: 0, ☐ Track Target, Uninjured Friends: 0, Injured Friends: 0, Neutrals: 0, Next Waypoint: 30, Alt. Waypoint: 0, Easy Going: 30, Cover: 0, Concealment: 0, ☐ Advance, Line Centre: 0, ☐ Clear Personalities, ☐ Only include moving agents
- Squad SA:** Enemy Threat 1: 0, Enemy Threat 2: 0, Enemy Threat 3: 75, Squad Friends: 0, Other Friends: 0, Neutrals: 0, Unknowns: 0
- Inorganic SA:** Enemy Threat 1: 0, Enemy Threat 2: 0, Enemy Threat 3: 55, Friends: 0, Neutrals: 0, Unknowns: 0
- Sensor Configuration:** Status of Sensors: 1 2 3 4 5 6, Sensor: 1, Master Enable: ☒, Sensor Model: ☒ Simple, ☐ Advanced, Class: ☒ A, ☐ B, ☐ Lock Parameter Values to Default State, Enable In This State: ☒, Detect. Range: 25000, Class. Range: 25000, ☒ Lock to Class. Range, Copy Sensor State Values, Paste Sensor State Values, Sensor Aperture: Arc 15 (degrees), Offset 0 (degrees), Load Sensor, Save Sensor

Figure 33. MANA Inputs for MMRC Agents in Default State

GENERAL

Side Name: MMRC Tender

Flag Icon: 0

No. of Agents: 1

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad: 0

INITIAL AGENT ORIENTATION

Bearing 0 (degrees)

Towards x = 0.0000 y = 0.0000 n. miles

Away From x = 0.0000 y = 0.0000 n. miles

Initial Scan Direction

Clockwise

Anti-clockwise

Random

MISCELLANEOUS

Terrain Affects Movement

Agents Allowed on Rooftops

Sound Fx

Goal

Fire

Die

GENERAL

Icon 11

Threat 2

Allegiance 1

Agent Class 0

Sensor Height 28 metres

Weight (Arb. units) 0.5

Movement Speed 0

FUEL

My Fuel Usage Rate (per second) 0

Refuel Trigger Range (metres) 5000

Prob Refuel Enemy 0

Prob Refuel Friend 100

Prob Refuel Neutral 0

SELF PROTECTION

No. Hits to Kill 100

Personal Concealment per Detection Event 0 %

Armour Thickness 0 mm

WAYPOINTS

Waypoint Radius: 2 metres

Dynamic Waypoint Radius: 1 metres

EMBUSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Embus Children

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA Squad SA Inorg. SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: 180 (degrees)

Respond if shot at, for time = 5 seconds

Copy Squad

Delete Squad

Save Squad

Load Squad

Agent SA:

	Min App.	Max. Inf.	
Enemies	0	100000	
Enemy Threat 1	0	100000	
Enemy Threat 2	0	100000	
Enemy Threat 3	0	100000	
Ideal Enemy	0	100000	
Uninjured Friends	0	100000	
Injured Friends	0	100000	
Neutrals	0	100000	
Next Waypoint	0	100000	
Alt. Waypoint	0	100000	
Easy Going	0	100000	
Cover	0	100000	
Concealment	0	100000	

En. Class 0

Track Target

Squad Only

All Friends

Cluster

Advance

Line Centre 0

Clear Personalities

Only include moving agents

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Squad Friends	0	100000
Other Friends	0	100000

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Friends	0	100000

Squad # 2

Jump

Default State

OK

Cancel

Status of Sensors: 1 2 3 4 5 6

Untitled

Sensor: 1

Master Enable

Sensor Model Simple Advanced

Class A B

Lock Parameter Values to Default State

Enable In This State

Copy Sensor State Values

Paste Sensor State Values

Sensor Ranges (metres)

Detect. Range 18500

Class. Range 18500

Lock to Class. Range

Sensor Aperture

Arc 360 (degrees)

Offset 0 (degrees)

Squad # 2

Jump

Default State

OK

Cancel

Figure 34. MANA Inputs for the MMRC Tender in Default State

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GENERAL

Side Name: Neutral Shipping Vessels

Flag Icon: 0

No. of Agents: 2

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad 0

INITIAL AGENT ORIENTATION

Bearing 0 (degrees)

Towards x = 0.0000 y = 0.0000 n. miles

Away From x = 0.0000 y = 0.0000 n. miles

Initial Scan Direction

Clockwise

Anti-clockwise

Random

MISCELLANEOUS

Terrain Affects Movement (Deselect for aircraft agents.)

Agents Allowed on Rooftops

Sound Fx

Goal

Fire

Die

Copy Squad

Delete Squad

Save Squad

Load Squad

GENERAL

Icon 111

Threat 3

Allegiance 0

Agent Class 0

Sensor Height 4 metres

Weight (Arb. units) 0.1

Movement Speed 12

km/hr

m/s

knots

FUEL

My Fuel Usage Rate (per second) 1

Refuel Trigger Range (metres) 0

Prob Refuel Enemy 0

Prob Refuel Friend 0

Prob Refuel Neutral 0

SELF PROTECTION

No. Hits to Kill 100

Personal Concealment per Detection Event 0 %

Armour Thickness 0 mm

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA

Squad SA

Inorg. SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: (degrees) 180

Respond if shot at, for time = 5 seconds

Set to Default State's Values

WAYPOINTS

Waypoint Radius: 200 metres

Dynamic Waypoint Radius: 1 metres

EMBUSSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Emboss Children

Embossing Radius: 1 metres

Squad # 6

Jump

Default State

OK

Cancel

Neutral Shipping Vessels

Agent SA:

Min App. Max. Inf.

Enemies -100 25000

Enemy Threat 1 0 25000

Enemy Threat 2 0 25000

Enemy Threat 3 0 25000

Ideal Enemy 0 25000

En. Class 0

Track Target

Uninjured Friends 33 50000

Injured Friends -38

Squad Only

All Friends

Cluster

Neutrals 0 100000

Next Waypoint 50 100000

Alt. Waypoint 0 100000

Advance

Easy Going 30 100000

Cover 0 100000

Concealment 0 100000

Line Centre 0

Clear Personalities

Only include moving agents

Squad SA:

Min App. Max. Inf.

Enemy Threat 1 0 100000

Enemy Threat 2 0 100000

Enemy Threat 3 0 100000

Squad Friends 0 100000

Other Friends 0 100000

Neutrals 0 100000

Unknowns 0 100000

Inorganic SA:

Min App. Max. Inf.

Enemy Threat 1 0 100000

Enemy Threat 2 0 100000

Enemy Threat 3 0 100000

Friends 0 100000

Neutrals 0 100000

Unknowns 0 100000

Squad # 6

Jump

Default State

OK

Cancel

Neutral Shipping Vessels

Status of Sensors: 1 2 3 4 5 6

Untitled

Sensor: 1

Master Enable

Sensor Model Simple Advanced

Class A B

Lock Parameter Values to Default State

Enable In This State

Copy Sensor State Values

Paste Sensor State Values

Sensor Ranges (metres)

Detect. Range 25000

Class. Range 25000

Lock to Class. Range

Sensor Aperture

Arc 15 (degrees)

Offset 0 (degrees)

Load Sensor

Save Sensor

Squad # 6

Jump

Default State

OK

Cancel

Neutral Shipping Vessels

Figure 35. MANA Inputs for the Supply Vessels in Default State

GENERAL

Side Name: Sea Plane

Flag Icon: 0

No. of Agents: 1

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad: 0

INITIAL AGENT ORIENTATION

Bearing

0 (degrees)

Towards

Away From

X = 0.0000

Y = 0.0000

n. miles

Initial Scan Direction

Clockwise

Anti-clockwise

Random

Copy Squad

Delete Squad

Save Squad

Load Squad

MISCELLANEOUS

Terrain Affects Movement (Deselect for aircraft agents.)

Agents Allowed on Rooftops

Sound Fx

Goal

Fire

Die

GENERAL

Icon: 9

Threat: 3

Allegiance: 1

Agent Class: 0

Sensor Height: 28 metres

Weight (Arb. units): 0.6

Movement Speed: 100

SELF PROTECTION

No. Hits to Kill: 100

Personal Concealment per Detection Event: 0 %

Armour Thickness: 0 mm

WAYPOINTS

Waypoint Radius: 200 metres

Dynamic Waypoint Radius: 1 metres

EMBUSSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Embuss Children

Embussing Radius: 1 metres

FUEL

My Fuel Usage Rate (per second): 1

Refuel Trigger Range (metres): 2000

Prob Refuel Enemy: 0

Prob Refuel Friend: 100

Prob Refuel Neutral: 0

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA Squad SA Inorg. SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: 180 (degrees)

Respond if shot at, for time = 5 seconds

Set to Default State's Values

Squad # 8

Jump

Default State

OK

Cancel

Sea Plane

Agent SA:

	Min App.	Max. Inf.	
Enemies	0	100000	Combat
Enemy Threat 1	0	100000	All distances are in metres.
Enemy Threat 2	0	100000	
Enemy Threat 3	0	100000	
Ideal Enemy	0	100000	En. Class: 0 Track Target
Uninjured Friends	50	100000	Squad Only All Friends Cluster
Injured Friends	0	100000	
Neutrals	0	100000	
Next Waypoint	68	100000	Advance
Alt. Waypoint	0	100000	
Easy Going	0	100000	Line Centre: 0
Cover	0	100000	Clear Personalities Only include moving agents
Concealment	0	100000	

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Squad Friends	0	100000
Other Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Squad # 8

Jump

Default State

OK

Cancel

Sea Plane

Status of Sensors: 1 2 3 4 5 6

Untitled

Sensor: 1 Master Enable

Sensor Model: Simple Advanced

Class: A B

Lock Parameter Values to Default State

Enable In This State

Copy Sensor State Values

Paste Sensor State Values

Sensor Ranges (metres)

Detect. Range: 50000

Class. Range: 50000

Lock to Class. Range

Sensor Aperture

Arc: 360 (degrees)

Offset: 0 (degrees)

Load Sensor Save Sensor

Figure 36. MANA Inputs for the Seaplane in Default State

GENERAL

Side Name: Zhaoyu WPS

Flag Icon: 0

No. of Agents: 5

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad: 0

INITIAL AGENT ORIENTATION

Bearing

0 (degrees)

Towards

Away From

x = 0.0000 y = 0.0000 n. miles

x = 0.0000 y = 0.0000 n. miles

Initial Scan Direction

Clockwise

Anti-clockwise

Random

Copy Squad

Delete Squad

Save Squad

Load Squad

GENERAL

Icon: 36

Threat: 3

Allegiance: 2

Agent Class: 0

Sensor Height: 2 metres

Weight (Arb. units): 0.3

Movement Speed: 14

km/hr

m/s

knots

SELF PROTECTION

No. Hits to Kill: 100

Personal Concealment per Detection Event: 0 %

Armour Thickness: 0 mm

WAYPOINTS

Waypoint Radius: 200 metres

Dynamic Waypoint Radius: 1 metres

EMBUSSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Emboss Children

Embossing Radius: 1 metres

FUEL

My Fuel Usage Rate (per second): 1

Refuel Trigger Range (metres): 0

Prob Refuel Enemy: 0

Prob Refuel Friend: 0

Prob Refuel Neutral: 0

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: (degrees): 180

Respond if shot at, for time = 5 seconds

Set to Default State's Values

Squad # 5

Zhaoyu WPS

Jump

Default State

OK

Cancel

Agent SA:

	Min App.	Max. Inf.
Enemies	-15	0
Enemy Threat 1	0	0
Enemy Threat 2	0	0
Enemy Threat 3	0	0
Ideal Enemy	0	0
Uninjured Friends	0	0
Injured Friends	0	0
Neutrals	100	0
Next Waypoint	50	0
Alt. Waypoint	0	0
Easy Going	35	0
Cover	0	0
Concealment	0	0

Move Constraints

Combat

All distances are in metres.

En. Class: 0

Track Target

Squad Only

All Friends

Cluster

Advance

Line Centre: 0

Clear Personalities

Only include moving agents

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	0
Enemy Threat 2	0	0
Enemy Threat 3	0	0
Squad Friends	0	0
Other Friends	0	0
Neutrals	100	0
Unknowns	0	0

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	0
Enemy Threat 2	0	0
Enemy Threat 3	0	0
Friends	0	0
Neutrals	0	0
Unknowns	0	0

Squad # 5

Zhaoyu WPS

Jump

Default State

OK

Cancel

Status of Sensors: 1 2 3 4 5 6

Untitled

Sensor: 1

Master Enable

Sensor Model: Simple

Advanced

Class: A

B

Lock Parameter Values to Default State

Sensor Ranges (metres)

Enable In This State

Detect. Range: 30000

Class. Range: 30000

Lock to Class. Range

Copy Sensor State Values

Paste Sensor State Values

Sensor Aperture

Arc: 20 (degrees)

Offset: 0 (degrees)

Load Sensor

Save Sensor

Squad # 5

Zhaoyu WPS

Jump

Default State

OK

Cancel

Figure 37. MANA Inputs for the Adversarial Ships in Default State

GENERAL

Side Name: EABO
Flag Icon: 0

No. of Agents: 1
Squad Active
Default State Icon:

FUEL TANK

Initial Fill: 200000
Agent is Auto-Refueller

EMBUS

Parent Squad: 0

INITIAL AGENT ORIENTATION

Bearing 0 (degrees)
Towards x = 0.0000 y = 0.0000 n. miles
Away From x = 0.0000 y = 0.0000 n. miles
Initial Scan Direction: Clockwise

MISCELLANEOUS

Terrain Affects Movement
Agents Allowed on Rooftops
Sound Fx: Fire, Die

GENERAL

Icon: 15
Threat: 3
Allegiance: 1
Agent Class: 0
Sensor Height: 28 metres
Weight (Arb. units): 0.6
Movement Speed: 0 km/hr, m/s, mph, knots

FUEL

My Fuel Usage Rate (per second): 0
Refuel Trigger Range (metres): 4500
Prob Refuel Enemy: 0
Prob Refuel Friend: 100
Prob Refuel Neutral: 0

SELF PROTECTION

No. Hits to Kill: 100
Personal Concealment per Detection Event: 0 %
Armour Thickness: 0 mm

WAYPOINTS

Waypoint Radius: 2 metres
Dynamic Waypoint Radius: 1 metres

EMBUSSING BEHAVIOUR

Release from Parent Squad
Release Child Squads
Embuss Children
Embussing Radius: 1 metres

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second
Face Enemy on: Agent SA, Squad SA, Inorg. SA
Face Unknowns on: Inorg. SA
In absence of enemy: No Change, Look in Direction of Movement, Patrol Mode, Scan 360 degrees, Scan Back and Forth, Scan Towards Direction of Movement, Patrol Scan Mode
Arc of Scan: 180 degrees
Respond if shot at, for time = 5 seconds

Squad # 3
EABO
Default State
OK Cancel

Agent SA:

	Min App.	Max. Inf.	Move Constraints
Enemies	0	100000	Combat
Enemy Threat 1	0	100000	All distances are in metres.
Enemy Threat 2	0	100000	
Enemy Threat 3	0	100000	
Ideal Enemy	0	100000	En. Class: 0 Track Target
Uninjured Friends	0	100000	Squad Only, All Friends, Cluster
Injured Friends	0	100000	
Neutrals	0	100000	
Next Waypoint	0	100000	Advance
Alt. Waypoint	0	100000	
Easy Going	0	100000	Line Centre: 0
Cover	0	100000	Clear Personalities, Only include moving agents
Concealment	0	100000	

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Squad Friends	0	100000
Other Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Status of Sensors: 1 2 3 4 5 6

Sensor: 1
Master Enable
Sensor Model: Simple, Advanced
Class: A, B
Lock Parameter Values to Default State

Sensor Ranges (metres)
Enable In This State
Detect. Range: 50000
Class. Range: 50000
Lock to Class. Range
Copy Sensor State Values
Paste Sensor State Values

Sensor Aperture
Arc: 360 (degrees)
Offset: 0 (degrees)
Load Sensor
Save Sensor

Squad # 3
FARO
Default State
OK Cancel

Squad # 3
EABO
Default State
OK Cancel

Figure 38. MANA Inputs for the EABO in Default State

B. CONFLICT

GENERAL
Side Name: F-18
Flag Icon: 0
No. of Agents: 4
Squad Active
Default State Icon:

FUEL TANK
Initial Fill: 200000
Agent is Auto-Refueller

MISCELLANEOUS
Terrain Affects Movement (Deselect for aircraft agents.)
Agents Allowed on Rooftops
Sound Fx
Goal
Fire
Die

EMBUS
Parent Squad 0

INITIAL AGENT ORIENTATION
Bearing 0 (degrees)
Towards
Away From
Initial Scan Direction
Clockwise
Anti-clockwise
Random

GENERAL
Icon 10
Threat 3
Allegiance 1
Agent Class 0
Sensor Height 28 metres
Weight (Arb. units) 0.6
Movement Speed 90 km/hr m/s mph knots

FUEL
My Fuel Usage Rate (per second) 1
Refuel Trigger Range (metres) 0
Prob Refuel Enemy 0
Prob Refuel Friend 0
Prob Refuel Neutral 0

SELF PROTECTION
No. Hits to Kill 1000
Personal Concealment per Detection Event 0 %
Armour Thickness 0 mm

ANGULAR MOVEMENT
Slew Rate: 180 degrees per second
Face Enemy on: Agent SA Squad SA Inorg. SA
Face Unknowns on: Inorg. SA

WAYPOINTS
Waypoint Radius: 5000 metres
Dynamic Waypoint Radius: 1 metres

EMBUSING BEHAVIOUR
Release from Parent Squad
Release Child Squads
Embuss Children
Embussing Radius: 1 metres

In absence of enemy
No Change
Look in Direction of Movement
Patrol Mode
Scan 360 degrees
Scan Back and Forth
Scan Towards Direction of Movement
Patrol Scan Mode
Arc of Scan: 180 degrees
Respond if shot at, for time = 5 seconds
Set to Default State's Values

Copy Squad
Delete Squad
Save Squad
Load Squad

Squad # 9
F-18
Jump
Default State
OK
Cancel

Agent SA:
Min App. Max. Inf. Move Constraints
Enemies 0 0 100000
Enemy Threat 1 0 0 100000
Enemy Threat 2 0 0 100000
Enemy Threat 3 0 0 100000
Ideal Enemy 0 0 100000
Uninjured Friends 0 0 100000
Injured Friends 0 0 100000
Neutrals 0 0 100000
Next Waypoint 78 0 100000
Alt. Waypoint 0 0 100000
Easy Going 0 0 100000
Cover 0 0 100000
Concealment 0 0 100000

All distances are in metres.
En. Class 0
Track Target
Squad Only
All Friends
Cluster
Advance
Line Centre 0
Clear Personalities
Only include moving agents

Squad SA:
Min App. Max. Inf.
Enemy Threat 1 0 0 100000
Enemy Threat 2 0 0 100000
Enemy Threat 3 0 0 100000
Squad Friends 0 0 100000
Other Friends 0 0 100000
Neutrals 0 0 100000
Unknowns 0 0 100000

Inorganic SA:
Min App. Max. Inf.
Enemy Threat 1 0 0 100000
Enemy Threat 2 0 0 100000
Enemy Threat 3 0 0 100000
Friends 0 0 100000
Neutrals 0 0 100000
Unknowns 0 0 100000

Squad # 9
F-18
Jump
Default State
OK
Cancel

Status of Sensors: 1 2 3 4 5 6
Untitled
Sensor: 1
Master Enable
Sensor Model Simple Advanced
Class A B
Lock Parameter Values to Default State

Sensor Ranges (metres)
Enable In This State
Detect. Range 60000
Class. Range 60000
Lock to Class. Range
Copy Sensor State Values
Paste Sensor State Values

Sensor Aperture
Arc 360 (degrees)
Offset 0 (degrees)

Figure 39. MANA Inputs for the F-18 in Default State

GENERAL

Side Name: MMRC Squad 1 Flag Icon: 0

No. of Agents: 2 Squad Active Default State Icon:

FUEL TANK

Initial Fill: 200000

☒ Agent is Auto-Refueller

MISCELLANEOUS

☒ Terrain Affects Movement (Deselect for aircraft agents.)

☐ Agents Allowed on Rooftops

EMBUS

Parent Squad 0

INITIAL AGENT ORIENTATION

☒ Bearing 0 (degrees)

☐ Towards $x = 0.0000$ $y = 0.0000$ n. miles

☐ Away From $x = 0.0000$ $y = 0.0000$ n. miles

☒ Clockwise

☐ Anti-clockwise

☐ Random

GENERAL

Icon 126 Threat 1

Allegiance 1 Agent Class 0

Sensor Height 4 metres Weight (Arb. units) 0.1

Movement Speed 20 km/hr m/s mph knots

FUEL

My Fuel Usage Rate (per second) 1

Refuel Trigger Range (metres) 2000

Prob Refuel Enemy 0

Prob Refuel Friend 0

Prob Refuel Neutral 100

SELF PROTECTION

No. Hits to Kill 2

Personal Concealment per Detection Event 0 %

Armour Thickness 0 mm

WAYPOINTS

Waypoint Radius: 500 metres

Dynamic Waypoint Radius: 1 metres

EMBUSING BEHAVIOUR

☒ Release from Parent Squad

☒ Release Child Squads

☐ Embuss Children

Embussing Radius: 1 metres

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: ☒ Agent SA ☐ Squad SA ☐ Inorg. SA

Face Unknowns on: ☐ Inorg. SA

In absence of enemy

☐ No Change

☐ Look in Direction of Movement

☐ Patrol Mode

☒ Scan 360 degrees

☐ Scan Back and Forth

☐ Scan Towards Direction of Movement

☐ Patrol Scan Mode

Arc of Scan: 180 degrees

☐ Respond if shot at, for time = 5 seconds

Set to Default State's Values

Agent SA:

	Min App.	Max. Inf.
Enemies	-45	25000
Enemy Threat 1	0	25000
Enemy Threat 2	0	25000
Enemy Threat 3	0	25000
Ideal Enemy	0	25000
Uninjured Friends	0	100000
Injured Friends	0	100000
Neutrals	0	100000
Next Waypoint	60	100000
Alt. Waypoint	0	100000
Easy Going	30	100000
Cover	0	100000
Concealment	0	100000

Move Constraints

☐ Combat

☐ Track Target

☐ Squad Only

☒ All Friends

☐ Cluster

☐ Advance

☐ Line Centre 0

☐ Clear Personalities

☐ Only include moving agents

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	-45	25000
Squad Friends	0	100000
Other Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	-45	25000
Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Status of Sensors: 1 2 3 4 5 6

See Friends

Sensor: 2 Master Enable

Sensor Model ☐ Simple ☒ Advanced

Class ☒ A ☐ B

☒ Lock Parameter Values to Default State

Sensor Ranges (metres)

☒ Enable In This State

Detect Range, R 10000

Avg Time Between Detections (r<=R) (seconds) 0

Classify Range, R 10000

Prob/Turn (r<=R) 1

Target Classes

☒ Target Specific Classes

Sensor Aperture

Arc 360 (degrees) Offset 0 (degrees)

Load Sensor Save Sensor

Weapon: 1 Master Enable

Weapon Model ☐ Simple ☐ Advanced

☒ Lock Parameter Values to Default State

Fire Mode/Target Kinetic Energy/Sqd SA

☒ Walls and Hills Block Fire

Shots/Ammo 10000 Reload Time -1 (seconds)

☒ Enable In This State

Shots per Second 100 /100 Armour Penetration 3 (mm)

Range, R (metres) 1800

Hit Rate per Discharge (r<=R) 1

☒ Fire on Closest Targets First

☐ Interpolate Within Subranges on SSKP Table

Shot Radius 0

Aperture Angle Arc: 360 Offset: 0

Load Wpn Save Wpn

Weapon: 2 Master Enable

Weapon Model ☐ Simple ☐ Advanced

☒ Lock Parameter Values to Default State

Fire Mode/Target Kinetic Energy/Sqd SA

☐ Walls and Hills Block Fire

Shots/Ammo 1000 Reload Time -1 (seconds)

☒ Enable In This State

Shots per Second 100 /100 Armour Penetration 3 (mm)

Range, R (metres) 1500

Hit Rate per Discharge (r<=R) 1

☒ Fire on Closest Targets First

☐ Interpolate Within Subranges on SSKP Table

Shot Radius 0

Aperture Angle Arc: 360 Offset: 0

Load Wpn Save Wpn

Figure 40. MANA Inputs for the MMRC in Default State

GENERAL

Side Name: MMRC Tender

Flag Icon: 0

No. of Agents: 1

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad: 0

INITIAL AGENT ORIENTATION

Bearing 0 (degrees)

Towards

0.0000 0.0000 n. miles

0.0000 0.0000 n. miles

Initial Scan Direction

Clockwise

Anti-clockwise

Random

MISCELLANEOUS

Terrain Affects Movement (Deselect for aircraft agents.)

Agents Allowed on Rooftops

Sound Fx

Goal

Fire

Die

GENERAL

Icon 11

Threat 2

Allegiance 1

Agent Class 0

Sensor Height 28 metres

Weight (Arb. units) 0.5

Movement Speed 0 km/hr

FUEL

My Fuel Usage Rate (per second) 0

Refuel Trigger Range (metres) 0

Prob Refuel Enemy 0

Prob Refuel Friend 0

Prob Refuel Neutral 0

SELF PROTECTION

No. Hits to Kill 100

Personal Concealment per Detection Event 100 %

Armour Thickness 0 mm

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: 180

Respond if shot at, for time = 5 seconds

WAYPOINTS

Waypoint Radius: 2 metres

Dynamic Waypoint Radius: 1 metres

EMBUSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Embuss Children

Embussing Radius: 1 metres

Copy Squad

Delete Squad

Save Squad

Load Squad

Squad # 1

MMRC Tender

Jump

Default State

OK

Cancel

Agent SA:

Enemies 0

Enemy Threat 1 0

Enemy Threat 2 0

Enemy Threat 3 0

Ideal Enemy 0

Uninjured Friends 0

Injured Friends 0

Neutrals 0

Next Waypoint 0

Alt. Waypoint 0

Easy Going 0

Cover 0

Concealment 0

Min App. 0

Max. Inf. 100000

Move Constraints

Combat

All distances are in metres.

En. Class 0

Track Target

Squad Only

All Friends

Cluster

Advance

Line Centre 0

Clear Personalities

Only include moving agents

Squad SA:

Enemy Threat 1 0

Enemy Threat 2 0

Enemy Threat 3 0

Squad Friends 0

Other Friends 0

Neutrals 0

Unknowns 0

Inorganic SA:

Enemy Threat 1 0

Enemy Threat 2 0

Enemy Threat 3 0

Friends 0

Neutrals 0

Unknowns 0

Min App. 0

Max. Inf. 100000

Squad # 1

MMRC Tender

Jump

Default State

OK

Cancel

Status of Sensors: 1 2 3 4 5 6

Untitled

Sensor: 1

Master Enable

Sensor Model Simple

Class A

Lock Parameter Values to Default State

Sensor Ranges (metres)

Enable In This State

Detect. Range 18500

Class. Range 18500

Lock to Class. Range

Copy Sensor State Values

Paste Sensor State Values

Sensor Aperture

Arc 360 (degrees)

Offset 0 (degrees)

Load Sensor

Save Sensor

Squad # 1

MMRC Tender

Jump

Default State

OK

Cancel

Status of Weapons: 1 2 3 4 5 6

Untitled

Class Pri

Weapon: 1

Master Enable

Weapon Model Simple

Fire Mode/Target Kinetic Energy/Agent SA

Lock Parameter Values to Default State

Walls and Hills Block Fire

Shots/Ammo 1000

Reload Time 1 (seconds)

Enable In This State

Shots per Second 100

Armour Penetration 0 (mm)

Copy Wpn State Values

Paste Wpn State Values

Range, R (metres)

Hit Rate per Discharge (r<R)

Fire on Closest Targets First

Interpolate Within Subranges on SSKP Table

Shot Radius 0

Aperture Angle

Arc 360

Offset 0

Load Wpn

Save Wpn

Figure 41. MANA Inputs for MMRC Tender in Default State

GENERAL
Side Name: Luyang Destroyers Flag Icon: 0
No. of Agents: 5 Squad Active Default State Icon:

FUEL TANK
Initial Fill: 200000
Agent is Auto-Refueller

MISCELLANEOUS
Terrain Affects Movement (Deselect for aircraft agents.)
☒ Agents Allowed on Rooftops

Sound Fx
☐ Goal ☒ Fire ☒ Die

EMBUSH
Parent Squad 0

INITIAL AGENT ORIENTATION
Bearing 0 (degrees)
Towards X = 0.0000 Y = 0.0000 n. miles
Away From X = 0.0000 Y = 0.0000 n. miles
Initial Scan Direction
☒ Clockwise ☐ Anti-clockwise ☐ Random

GENERAL
Icon 36 Threat 3
Allegiance 2 Agent Class 0
Sensor Height 2 metres Weight (Arb. units) 0.5
Movement Speed 20 km/hr m/s mph knots

FUEL
My Fuel Usage Rate (per second) 1
Refuel Trigger Range (metres) 0
Prob Refuel Enemy 0
Prob Refuel Friend 0
Prob Refuel Neutral 0

SELF PROTECTION
No. Hits to Kill 5
Personal Concealment per Detection Event 0 %
Armour Thickness 30 mm

ANGULAR MOVEMENT
Slew Rate: 180 degrees per second
Face Enemy on: ☒ Agent SA ☒ Squad SA ☐ Inorg. SA
Face Unknowns on: ☐ Inorg. SA

WAYPOINTS
Waypoint Radius: 800 metres
Dynamic Waypoint Radius: 1 metres

EMBUSHING BEHAVIOUR
☒ Release from Parent Squad
☒ Release Child Squads
☐ Embuss Children
Embussing Radius: 1 metres

ANGULAR MOVEMENT
In absence of enemy
☐ No Change
☐ Look in Direction of Movement
☐ Patrol Mode
☒ Scan 360 degrees
☐ Scan Back and Forth
☐ Scan Towards Direction of Movement
☐ Patrol Scan Mode
Arc of Scan: 180 degrees
☐ Respond if shot at, for time = 5 seconds
Set to Default State's Values

Copy Squad Delete Squad Save Squad Load Squad

Squad # 4 Luyang Destroyers Default State OK Cancel

Agent SA:
Enemies 30 Min App. 0 Max. Inf. 100000
Enemy Threat 1 0 0 100000
Enemy Threat 2 0 0 100000
Enemy Threat 3 0 0 100000
Ideal Enemy 0 0 100000
Uninjured Friends 0 0 100000
Injured Friends 0 0 100000
Neutrals 0 0 100000
Next Waypoint 70 0 100000
Alt. Waypoint 0 0 100000
Easy Going 35 0 100000
Cover 0 0 100000
Concealment 0 0 100000
En. Class 0 Track Target
☒ Squad Only ☐ All Friends
Cluster 0 Value 10000
Advance
Line Centre 0
Clear Personalities
☐ Only include moving agents

Squad SA:
Enemy Threat 1 0 0 100000
Enemy Threat 2 0 0 100000
Enemy Threat 3 30 0 100000
Squad Friends 0 0 100000
Other Friends 0 0 100000
Neutrals 0 0 100000
Unknowns 0 0 100000

Inorganic SA:
Enemy Threat 1 0 0 100000
Enemy Threat 2 0 0 100000
Enemy Threat 3 30 0 100000
Friends 0 0 100000
Neutrals 0 0 100000
Unknowns 0 0 100000

Status of Sensors: 1 2 3 4 5 6 Untitled
Sensor: 1 Master Enable
Sensor Model Simple Advanced
Class A B
☒ Lock Parameter Values to Default State
Sensor Ranges (metres)
Detect. Range 10000
Class. Range 10000
Lock to Class. Range
Copy Sensor State Values
Paste Sensor State Values
Sensor Aperture
Arc 20 (degrees) Offset 0 (degrees)
Load Sensor Save Sensor

Squad # 4 Luyang Destroyers Default State OK Cancel

Status of Weapons: 1 2 3 4 5 6 MK45 Class Pri Sec
Weapon: 1 Master Enable
Weapon Model Simple Advanced
☒ Lock Parameter Values to Default State
Fire Mode/Target Kinetic Energy/Agent SA
☒ Walls and Hills Block Fire
Shots/Ammo 10 Reload Time -1 (seconds)
Enable In This State
Shots per Second 100 /100 Armour Penetration 2 (mm)
Range, R (metres) 24000
Hit Rate per Discharge (r<-R) 1
Copy Wpn State Values
Paste Wpn State Values
Fire on Closest Targets First
Interpolate Within Subranges on SSKP Table
Shot Radius 0
Aperture Angle
Arc: 360
Offset: 0
Load Wpn Save Wpn

Squad # 4 Luyang Destroyers Default State OK Cancel

Status of Weapons: 1 2 3 4 5 6 VLS Class Pri Sec
Weapon: 2 Master Enable
Weapon Model Simple Advanced
☒ Lock Parameter Values to Default State
Fire Mode/Target Kinetic Energy/Sqd & Inorg SA
☐ Walls and Hills Block Fire
Shots/Ammo 20 Reload Time -1 (seconds)
Enable In This State
Shots per Second 100 /100 Armour Penetration 20 (mm)
Range, R (metres) 375400
Hit Rate per Discharge (r<-R) 0
Copy Wpn State Values
Paste Wpn State Values
Fire on Closest Targets First
Interpolate Within Subranges on SSKP Table
Shot Radius 0
Aperture Angle
Arc: 360
Offset: 0

Status of Weapons: 1 2 3 4 5 6 CIWS Class Pri Sec
Weapon: 3 Master Enable
Weapon Model Simple Advanced
☒ Lock Parameter Values to Default State
Fire Mode/Target Kinetic Energy/Agent SA
☒ Walls and Hills Block Fire
Shots/Ammo 100000 Reload Time -1 (seconds)
Enable In This State
Shots per Second 7500 /100 Armour Penetration 0 (mm)
Range, R (metres) 1400
Hit Rate per Discharge (r<-R) 1
Copy Wpn State Values
Paste Wpn State Values
Fire on Closest Targets First
Interpolate Within Subranges on SSKP Table
Shot Radius 0
Aperture Angle
Arc: 360
Offset: 0

Figure 42. MANA Inputs for the Adversarial Ships in Default State

GENERAL

Side Name: EABO

Flag Icon: 0

No. of Agents: 1

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad: 0

INITIAL AGENT ORIENTATION

Bearing: 0 (degrees)

Towards: X = 0.0000 Y = 0.0000 n. miles

Away From: X = 0.0000 Y = 0.0000 n. miles

MISCELLANEOUS

Terrain Affects Movement (Deselect for aircraft agents.)

Agents Allowed on Rooftops

Sound FX

Goal

Fire

Die

Copy Squad

Delete Squad

Save Squad

Load Squad

Squad # 2

EABO

Jump

Default State

OK

Cancel

GENERAL

Icon: 15

Threat: 2

Allegiance: 1

Agent Class: 0

Sensor Height: 28 metres

Weight (Arb. units): 0.6

Movement Speed: 0 km/hr m/s mph knots

SELF PROTECTION

No. Hits to Kill: 100

Personal Concealment per Detection Event: 0 %

Armour Thickness: 0 mm

WAYPOINTS

Waypoint Radius: 2 metres

Dynamic Waypoint Radius: 1 metres

EMBUSSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Embuss Children

Embussing Radius: 1 metres

FUEL

My Fuel Usage Rate (per second): 0

Refuel Trigger Range (metres): 0

Prob Refuel Enemy: 0

Prob Refuel Friend: 0

Prob Refuel Neutral: 0

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA Squad SA Inorg. SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: 180 (degrees)

Respond if shot at, for time = 5 seconds

Set to Default State's Values

Squad # 2

EABO

Jump

Default State

OK

Cancel

Agent SA:

	Min App.	Max. Inf.
Enemies	0	100000
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Ideal Enemy	0	100000
Uninjured Friends	0	100000
Injured Friends	0	100000
Neutrals	0	100000
Next Waypoint	0	100000
Alt. Waypoint	0	100000
Easy Going	0	100000
Cover	0	100000
Concealment	0	100000

Move Constraints

Combat

All distances are in metres.

En. Class: 0

Track Target

Squad Only

All Friends

Cluster

Advance

Line Centre: 0

Clear Personalities

Only include moving agents

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Squad Friends	0	100000
Other Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	100000
Enemy Threat 2	0	100000
Enemy Threat 3	0	100000
Friends	0	100000
Neutrals	0	100000
Unknowns	0	100000

Squad # 2

EABO

Jump

Default State

OK

Cancel

Status of Weapons: 1 2 3 4 5 6

Untitled

Class: Pri Sec

Weapon: 1

Master Enable

Lock Parameter Values to Default State

Fire Mode/Target: Kinetic Energy/Agent SA

Walls and Hills Block Fire

Shots/Ammo: 1000

Reload Time: -1 (seconds)

Enable In This State

Shots per Second: 100 /100

Armour Penetration: 0 (mm)

Copy Wpn State Values

Paste Wpn State Values

Range, R (metres): 200

Hit Rate per Discharge (r->R): 1

Fire on Closest Targets First

Interpolate Within Subranges on SSKP Table

Shot Radius: 0

Aperture Angle

Arc: 360 (degrees)

Offset: 0

Load Wpn

Save Wpn

Squad # 2

EABO

Jump

Default State

OK

Cancel

Status of Sensors: 1 2 3 4 5 6

Untitled

Sensor: 1

Master Enable

Lock Parameter Values to Default State

Sensor Model: Simple Advanced

Class: A B

Enable In This State

Detect. Range: 50000

Class. Range: 50000

Lock to Class. Range

Copy Sensor State Values

Paste Sensor State Values

Sensor Ranges (metres)

Sensor Aperture

Arc: 360 (degrees)

Offset: 0 (degrees)

Load Sensor

Save Sensor

Squad # 2

EABO

Jump

Default State

OK

Cancel

Figure 43. MANA Inputs for the EABO in Default State

GENERAL

Side Name: Flag Icon:

No. of Agents: ☒ Squad Active Default State Icon:

FUEL TANK

Initial Fill:

☐ Agent is Auto-Refueller

EMBUS

Parent Squad

MISCELLANEOUS

☒ Terrain Affects Movement (Deselect for aircraft agents.) ☐ Agents Allowed on Rooftops

Sound Fx: ☐ Goat ☒ Fire ☒ Die

INITIAL AGENT ORIENTATION

☒ Bearing (degrees) ☐ Towards n. miles ☐ Away From n. miles

Initial Scan Direction: ☒ Clockwise ☐ Anti-clockwise ☐ Random

☒ Copy Squad ☒ Delete Squad ☒ Save Squad ☐ Load Squad

GENERAL

Icon Threat Agent Class

Allegiance Sensor Height metres Weight (Arb. units)

Movement Speed km/hr

SELF PROTECTION

No. Hits to Kill Personal Concealment per Detection Event % Armour Thickness mm

WAYPOINTS

Waypoint Radius: metres Dynamic Waypoint Radius: metres

EMBUSSING BEHAVIOUR

☒ Release from Parent Squad ☒ Release Child Squads ☐ Embuss Children

Embussing Radius: metres

ANGULAR MOVEMENT

Slew Rate: degrees per second

Face Enemy on: ☒ Agent SA ☒ Squad SA ☐ Inorg. SA

Face Unknowns on: ☒ Inorg. SA

In absence of enemy: ☐ No Change ☐ Look in Direction of Movement ☒ Patrol Mode ☐ Scan 360 degrees ☐ Scan Back and Forth ☐ Scan Towards Direction of Movement ☐ Patrol Scan Mode

Arc of Scan: (degrees)

☐ Respond if shot at, for time = seconds

Status of Sensors: 1 2 3 4 5 6 Class ☐ Simple ☐ Advanced

Sensor: 1 ☒ Master Enable ☐ Lock Parameter Values to Default State

Sensor Ranges (metres)

Enable In This State ☒ Detect. Range Class. Range Lock to Class. Range ☐

Sensor Aperture

Arc (degrees) Offset (degrees)

Status of Weapons: 1 2 3 4 5 6 Class ☒ Pri ☐ Sec

Weapon: 1 ☒ Master Enable ☐ Lock Parameter Values to Default State

Weapon Model ☒ Simple ☐ Advanced

Fire Mode/Target ☒ Walls and Hills Block Fire

Shots/Ammo Reload Time (seconds)

Enable In This State ☒ Shots per Second /100 Armour Penetration (mm)

Range, R (metres) Hit Rate per Discharge (r--R)

☒ Fire on Closest Targets First ☐ Interpolate Within Subranges on SSKP Table

Shot Radius

Aperture Angle: Arc: Offset:

Status of Weapons: 1 2 3 4 5 6 Class ☒ Pri ☐ Sec

Weapon: 3 ☒ Master Enable ☐ Lock Parameter Values to Default State

Weapon Model ☒ Simple ☐ Advanced

Fire Mode/Target ☒ Walls and Hills Block Fire

Shots/Ammo Reload Time (seconds)

Enable In This State ☒ Shots per Second /100 Armour Penetration (mm)

Range, R (metres) Hit Rate per Discharge (r--R)

☒ Fire on Closest Targets First ☐ Interpolate Within Subranges on SSKP Table

Shot Radius

Aperture Angle: Arc: Offset:

Squad # 7 Default State

Agent SA:

	Min App.	Max. Inf.
Enemies	60	0
Enemy Threat 1	0	0
Enemy Threat 2	0	0
Enemy Threat 3	0	0
Ideal Enemy	0	0
Uninjured Friends	0	0
Injured Friends	0	0
Neutrals	0	0
Next Waypoint	90	0
Alt. Waypoint	0	0
Easy Going	0	0
Cover	0	0
Concealment	0	0

Move Constraints: ☐ Combat

All distances are in metres.

En. Class ☒ Track Target

☒ Squad Only ☐ All Friends ☐ Cluster

☐ Advance

Line Centre

☐ Only include moving agents

Squad SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	0
Enemy Threat 2	0	0
Enemy Threat 3	40	0
Squad Friends	0	0
Other Friends	0	0
Neutrals	0	0
Unknowns	0	0

Inorganic SA:

	Min App.	Max. Inf.
Enemy Threat 1	0	0
Enemy Threat 2	0	0
Enemy Threat 3	20	0
Friends	0	0
Neutrals	0	0
Unknowns	0	0

Status of Weapons: 1 2 3 4 5 6 Class ☒ Pri ☐ Sec

Weapon: 1 ☒ Master Enable ☐ Lock Parameter Values to Default State

Weapon Model ☒ Simple ☐ Advanced

Fire Mode/Target ☒ Walls and Hills Block Fire

Shots/Ammo Reload Time (seconds)

Enable In This State ☒ Shots per Second /100 Armour Penetration (mm)

Range, R (metres) Hit Rate per Discharge (r--R)

☒ Fire on Closest Targets First ☐ Interpolate Within Subranges on SSKP Table

Shot Radius

Aperture Angle: Arc: Offset:

Squad # 7 Default State

Figure 44. MANA Inputs for the Cruiser in Default State

GENERAL

Side Name: DDG

Flag Icon: 0

No. of Agents: 2

Squad Active

Default State Icon:

FUEL TANK

Initial Fill: 200000

Agent is Auto-Refueller

EMBUS

Parent Squad 0

INITIAL AGENT ORIENTATION

Bearing 0 (degrees)

Towards x = 0.0000 y = 0.0000 n. miles

Away From x = 0.0000 y = 0.0000 n. miles

Initial Scan Direction

Clockwise

Anti-clockwise

Random

MISCELLANEOUS

Terrain Affects Movement (Deselect for aircraft agents.)

Agents Allowed on Rooftops

Sound FX

Goal

Fire

Die

Copy Squad

Delete Squad

Save Squad

Load Squad

GENERAL

Icon 11

Threat 3

Allegiance 1

Agent Class 0

Sensor Height 28 metres

Weight (Arb. units) 0.8

Movement Speed 20

km/hr

m/s

mph

knots

SELF PROTECTION

No. Hits to Kill 6

Personal Concealment per Detection Event 0 %

Armour Thickness 30 mm

WAYPOINTS

Waypoint Radius: 500 metres

Dynamic Waypoint Radius: 1 metres

EMBUSSING BEHAVIOUR

Release from Parent Squad

Release Child Squads

Emboss Children

Embossing Radius: 1 metres

ANGULAR MOVEMENT

Slew Rate: 180 degrees per second

Face Enemy on: Agent SA Squad SA Inorg. SA

Face Unknowns on: Inorg. SA

In absence of enemy

No Change

Look in Direction of Movement

Patrol Mode

Scan 360 degrees

Scan Back and Forth

Scan Towards Direction of Movement

Patrol Scan Mode

Arc of Scan: 180 (degrees)

Respond if shot at, for time = 10 seconds

Set to Default State's Values

FUEL

My Fuel Usage Rate (per second)

Refuel Trigger Range (metres)

Prob Refuel Enemy 0

Prob Refuel Friend 0

Prob Refuel Neutral 0

Squad # 8

Jump

Default State

OK

Cancel

Agent SA:

Min App. Max. Inf.

Enemies 50 0 100000

Enemy Threat 1 0 0 100000

Enemy Threat 2 0 0 100000

Enemy Threat 3 0 0 100000

Ideal Enemy 0 0 100000

Uninjured Friends 0 0 100000

Injured Friends 0 0 100000

Neutrals 0 0 100000

Next Waypoint 90 0 100000

Alt. Waypoint 0 0 100000

Easy Going 0 0 100000

Cover 0 0 100000

Concealment 0 0 100000

Move Constraints

Combat

All distances are in metres.

En. Class 0

Track Target

Squad Only

All Friends

Cluster

Advance

Line Centre 0

Clear Personalities

Only include moving agents

Squad SA:

Min App. Max. Inf.

Enemy Threat 1 0 0 100000

Enemy Threat 2 0 0 100000

Enemy Threat 3 40 0 100000

Squad Friends 0 0 100000

Other Friends 0 0 100000

Neutrals 0 0 100000

Unknowns 0 0 100000

Inorganic SA:

Min App. Max. Inf.

Enemy Threat 1 0 0 100000

Enemy Threat 2 0 0 100000

Enemy Threat 3 50 0 100000

Friends 0 0 100000

Neutrals 0 0 100000

Unknowns 0 0 100000

Status of Weapons: 1 2 3 4 5 6

MK45

Class Pri Sec

Weapon: 1

Master Enable

Weapon Model Simple Advanced

Lock Parameter Values to Default State

Fire Mode/Target Kinetic Energy/Sqd & Inorg SA

Walls and Hills Block Fire

Shots/Ammo 20

Reload Time -1 (seconds)

Enable In This State

Shots per Second 100 /100

Armour Penetration 5 (mm)

Copy Wpn State Values

Paste Wpn State Values

Fire on Closest Targets First

Interpolate Within Subranges on SSKP Table

Shot Radius 0

Aperture Angle

Arc: 360

Offset: 0

Status of Weapons: 1 2 3 4 5 6

AN/SPY-6

Class A B

Weapon: 1

Master Enable

Sensor Model Simple Advanced

Lock Parameter Values to Default State

Sensor Ranges (metres)

Detect. Range 100000

Class. Range 100000

Lock to Class. Range

Copy Sensor State Values

Paste Sensor State Values

Sensor Aperture

Arc 360 (degrees)

Offset 0 (degrees)

Status of Weapons: 1 2 3 4 5 6

CIWS

Class Pri Sec

Weapon: 2

Master Enable

Weapon Model Simple Advanced

Lock Parameter Values to Default State

Fire Mode/Target Kinetic Energy/Agent SA

Walls and Hills Block Fire

Shots/Ammo 100000

Reload Time -1 (seconds)

Enable In This State

Shots per Second 100 /100

Armour Penetration 5 (mm)

Copy Wpn State Values

Paste Wpn State Values

Fire on Closest Targets First

Interpolate Within Subranges on SSKP Table

Shot Radius 0

Aperture Angle

Arc: 360

Offset: 0

Status of Weapons: 1 2 3 4 5 6

SM-2

Class Pri Sec

Weapon: 3

Master Enable

Weapon Model Simple Advanced

Lock Parameter Values to Default State

Fire Mode/Target Kinetic Energy/Sqd & Inorg SA

Walls and Hills Block Fire

Shots/Ammo 15

Reload Time 60 (seconds)

Enable In This State

Shots per Second 100 /100

Armour Penetration 20 (mm)

Copy Wpn State Values

Paste Wpn State Values

Fire on Closest Targets First

Interpolate Within Subranges on SSKP Table

Shot Radius 0

Aperture Angle

Arc: 360

Offset: 0

Figure 45. MANA Inputs for the DDG in Default State

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APPENDIX B. DOE VALUES

A. COMPETITION

Table 19. Design Points for Competition Design of Experiments

Design Point	MMRC Sensor Classification Range	MMRC Sensor Aperture Range	# MMRCs Forward Scouting	# MMRCs Patrolling	# MMRCs Convoy Protection	Total MMRC Fuel	Red Deterrence
1	45000	12	2	1	3	225000	-66
2	42656	30	1	2	2	137500	-63
3	41875	19	3	1	1	218750	-64
4	34063	28	3	2	3	131250	-59
5	43438	11	2	1	2	243750	-80
6	44219	29	2	2	2	143750	-92
7	37188	19	3	2	1	231250	-81
8	33281	24	3	2	3	150000	-89
9	36406	15	1	2	2	162500	-100
10	38750	23	2	2	1	206250	-95
11	37969	14	3	3	2	112500	-94
12	39531	24	2	3	3	293750	-77
13	34844	13	1	2	2	125000	-52
14	41094	22	2	3	1	212500	-53
15	35625	14	3	3	2	100000	-67
16	40313	23	2	3	3	281250	-72
17	32500	20	2	2	2	200000	-75
18	20000	28	2	3	1	175000	-84
19	22344	10	3	2	2	262500	-88
20	23125	21	1	3	3	181250	-86
21	30938	13	1	2	1	268750	-91
22	21563	29	2	3	2	156250	-70
23	20781	11	2	2	2	256250	-58
24	27813	21	1	3	3	168750	-69
25	31719	16	1	2	1	250000	-61
26	28594	25	3	2	2	237500	-50
27	26250	17	2	2	3	193750	-55
28	27031	26	2	1	2	287500	-56
29	25469	16	2	1	2	106250	-73
30	30156	27	3	2	2	275000	-98
31	23906	18	2	1	3	187500	-97
32	29375	26	1	1	2	300000	-83
33	24688	18	2	1	1	118750	-78

B. CONFLICT

Table 20. Design Points for Conflict Design of Experiments

Design Point	MMRC Sensor Classification Range	MMRC Sensor Aperture Range	# MMRCs in Patrol Group	MMRC M240B Firing Range	MMRC Hits to Kill	Adversarial MK45 Firing Range
1	45000	12	2	1281	4	26250
2	42656	30	1	1563	3	21875
3	41875	19	3	1234	2	25938
4	34063	28	3	1609	4	21563
5	43438	11	2	1328	3	27188
6	44219	29	2	1422	3	22188
7	37188	19	3	1375	2	26563
8	33281	24	3	1516	4	22500
9	36406	15	1	1797	3	23125
10	38750	23	2	2031	2	25313
11	37969	14	3	2453	3	20625
12	39531	24	2	2406	4	29688
13	34844	13	1	1844	3	21250
14	41094	22	2	2313	2	25625
15	35625	14	3	2359	3	20000
16	40313	23	2	2500	4	29063
17	32500	20	2	1750	3	25000
18	20000	28	2	2219	2	23750
19	22344	10	3	1938	3	28125
20	23125	21	1	2266	4	24063
21	30938	13	1	1891	2	28438
22	21563	29	2	2172	3	22813
23	20781	11	2	2078	3	27813
24	27813	21	1	2125	4	23438
25	31719	16	1	1984	2	27500
26	28594	25	3	1703	3	26875
27	26250	17	2	1469	4	24688
28	27031	26	2	1047	3	29375
29	25469	16	2	1094	3	20313
30	30156	27	3	1656	3	28750
31	23906	18	2	1188	4	24375
32	29375	26	1	1141	3	30000
33	24688	18	2	1000	2	20938

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