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ANALYSIS AND ASSESSMENT OF LETHALITY AND SURVIVABILITY FOR THE MARINE LITTORAL REGIMENT

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ANALYSIS AND ASSESSMENT OF LETHALITY AND SURVIVABILITY FOR THE MARINE LITTORAL REGIMENT

by

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June 2022

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As the Marine Corps activates the Marine Littoral Regiment (MLR) to serve as the joint force's reconnaissance and counter-reconnaissance effort, questions abound regarding the MLR's ability to provide a persistent and lethal presence well inside the reach of our adversaries' advanced long-range precision fires. In this study, the author uses agent-based combat simulations to inform future force design decisions, live-force experimentation, and tactics. The simulated scenario imagines a future MLR conducting sea control operations in the littorals of the Western Pacific against a peer naval threat. This research investigates the effect that a guard force of autonomous and/or semi-autonomous surface vessels, operating as the guard force of the MLR's defense in depth, has on the survivability and lethality of the MLR's land-based anti-ship missile platforms. Summary statistics generated by the simulation indicate that the future battlefield will see high losses on both sides. However, based on the results of 27,200 simulated engagements, this study finds that an MLR using a guard force of armed and unarmed "scouts" as described above can inflict a prohibitively high and unsustainable cost on an enemy naval force.

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ANALYSIS AND ASSESSMENT OF LETHALITY AND SURVIVABILITY FOR THE MARINE LITTORAL REGIMENT

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

As the Marine Corps activates the Marine Littoral Regiment (MLR) to serve as the joint force's reconnaissance and counter-reconnaissance effort, questions abound regarding the MLR's ability to provide a persistent and lethal presence well inside the reach of our adversaries' advanced long-range precision fires. In this study, the author uses agent-based combat simulations to inform future force design decisions, live-force experimentation, and tactics. The simulated scenario imagines a future MLR conducting sea control operations in the littorals of the Western Pacific against a peer naval threat. This research investigates the effect that a guard force of autonomous and/or semi-autonomous surface vessels, operating as the guard force of the MLR's defense in depth, has on the survivability and lethality of the MLR's land-based anti-ship missile platforms. Summary statistics generated by the simulation indicate that the future battlefield will see high losses on both sides. However, based on the results of 27,200 simulated engagements, this study finds that an MLR using a guard force of armed and unarmed "scouts" as described above can inflict a prohibitively high and unsustainable cost on an enemy naval force.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	Anti-Access, Area Denial
ASEAN	Association of Southeast Asian Nations
ASM	Anti-Ship Missiles
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CMC	Commandant of the Marine Corps
CPG	Commandant’s Planning Guidance
DOD	Department of Defense
EABO	Expeditionary Advanced Base Operations
EW	Electronic Warfare
FEBA	Forward Edge of the Battle Area
FIC	First Island Chain
FOB	Forward Operating Base
G/ATOR	Ground/Air Task Oriented Radar
GBASM	Ground Based Anti-Ship Missile
INDOPACOM	Indo-Pacific Command
LAAB	Littoral Anti-Air Battalion
LCT	Littoral Combat Team
LLB	Littoral Logistics Battalion
LMACC	Lightly Manned Autonomous Combat Capability
LOCE	Littoral Operations in a Contested Environment
LRASM	Long Range Anti-Ship Missile
LRUSV	Long-Range Unmanned Surface Vessel
MADIS	Marine Air Defense Integrated System
MAST	Modeling and Simulation Toolbox
MLR	Marine Littoral Regiment
MUSV	Medium Unmanned Surface Vessel
NDS	National Defense Strategy
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom

OPF	Organic Precision Fires
PLAN	People’s Liberation Army Navy
PRC	People’s Republic of China
PTT	Procedures, Techniques, and Tactics
SAG	Surface Action Group
SCS	South China Sea
SIF	Stand-in Force
SSP	Scout Sniper Platoon
SUAS	Small Unmanned Aerial System
UAV	Unmanned Aerial Vehicles
USMC	United States Marine Corps
USN	United States Navy
WEZ	Weapon Engagement Zone

EXECUTIVE SUMMARY

In 2019, the United States Marine Corps (USMC) committed itself to pursuing historic organizational changes with the intent of becoming the preeminent reconnaissance and counter-reconnaissance force in the Western Pacific. To accomplish this goal, the Marine Corps published Force Design 2030 and is currently procuring new combat systems and creating a new table of organization to gain and maintain lethality in geographically remote and environmentally austere locations.

One of the principal units of action in Force Design 2030 is the Marine Littoral Regiment (MLR). The MLR contains infantry, rocket artillery, air defense, logistics, and command and control units and, in the words of the Commandant of the Marine Corps, is "optimized for naval expeditionary warfare in contested spaces, purpose-built to facilitate sea denial and assured access in support of the fleets" (Berger 2019, p. 5). However, the first MLR has been only recently activated, and therefore questions proliferate regarding the capabilities and limitations of the MLR.

Of particular interest is the littoral guard force employment to conduct reconnaissance and counter-reconnaissance in the MLR's security area. This research aims to examine the MLR capabilities in various physical settings and against contemporary peer naval threats to help inform decision making regarding the most lethal composition and employment method for the MLR's guard force. To this end, the author seeks to answer the following questions:

1. Does integrating a guard force of autonomous and semi-autonomous vessels into the MLR's defense in depth increase the lethality and survivability of friendly land-based units? Additionally, what friendly factors contribute to the guard force's survivability and lethality?
2. Which factors of the guard force have the most impact on the MLR's ability to detect, report, and engage an enemy surface force before the enemy force can detect and engage land-based friendly units?

3. Can the use of autonomous and semi-autonomous vessels to detect and strike an enemy surface force increase the MLR's ability to attrite enemy ships?

Using the Modeling and Simulation Toolbox (MAST) developed at Naval Surface Warfare Center, we use cutting-edge design of experiments to efficiently execute 27,250 simulated battles between a MLR and a People's Liberation Army Navy (PLAN) surface action group (SAG). Figure 1 depicts the modeling environment and some of the agents in the simulation.

Figure 1. Simulated engagement between MLR guard force and PLAN surface combatants

In each simulated engagement, the MLR was tasked with conducting a sea denial mission in which they attempted to maximize the number of enemy ships destroyed while simultaneously preserving combat power. The MLR employed a guard force with the following baseline composition: four Lightly Manned Autonomous Combat Capability (LMACC) vessels, five Medium Unmanned Surface Vessels (MUSV), and 15 Long Range Unmanned Surface Vessels (LRUSV). The quantity of each vessel varied throughout the experiment to evaluate the efficacy of different vessel combinations. The guard force's mission was to "protect the main force from attack, direct fire, and ground observation by fighting to gain time, while also observing and reporting information" (MCDP 1-0, p. 11-13). To evaluate guard force's impact on friendly survivability and lethality, we varied the quantity of vessel type, each vessel type's position, and the vessels' sensor capabilities. We used efficient design of experiments to explore the effect of various combinations of the factors mentioned above.

From the 27,250 simulated engagements, we observed a few trends that not only answered our research questions, but also presented the opportunity to inform Force Design 2030 decisions and initiatives:

- Guard force composition: LMACC quantity is a dominant factor in predicting both survivability and lethality. The LMACC is a small missile combatant, lightly manned, with highly autonomous ship systems. It may be configured for many roles, but in this case, strike. An analysis of the experiment's output indicates that the guard force should have no fewer than six LMACCs.

- Lethality: employing the LMACC closer to shore (10-15 nautical miles), with the LRUSV deployed at a deeper position (100 nm), results in fewer GBASM launchers destroyed and more PLAN ships destroyed.

- Pairing the LMACC with a smaller platform that can act as a scout for the LMACC yields more favorable friendly outcomes. To this end, equipping the LRUSV with the capability to detect enemy ships—using either passive or visual sensors—at longer ranges allows the LRUSV to communicate information on the enemy's composition and disposition earlier and more accurately.

- Both sides in a modern conflict should expect high attrition. The variability in the exact percentages is high due to the inherent uncertainty of combat, but the mean number of GBASM launchers destroyed in the experiment is 15.62 out of 36.

The intent of this study is to further the discussion about the composition, capabilities, and employment of the MLR while simultaneously stimulating new research to inform future force design decisions, live-fire experimentation, and tactics.

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United States Marine Corps (2019) Marine Corps operations. MCDP 1-0 w/ Ch 1–3, Washington, DC. https://www.marines.mil/News/Publications/MCPEL/Electronic-Library-Display/Article/1323621/mcdp-1-0-w-ch1-3/

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I. INTRODUCTION

Through the first two decades of the 21st century, multiple generations of Marines fought insurgencies in Afghanistan and Iraq. While lethal in their own right, insurgencies lack the ability to apply combat power across multiple domains—air, land, sea, cyber, space, and information—simultaneously and in a manner which challenges the supremacy of the United States in those domains. Multiple editions of the National Defense Strategy (NDS) have signaled a significant shift away from counterinsurgency campaigns and towards competition with peer or near-peer adversaries. One of these possible conflicts could occur with the People's Republic of China (PRC) in the South China Sea (SCS). Unlike the aforementioned insurgencies, the PRC is capable of, and apparently is willing to, apply combat power across multiple domains which *will* threaten the strategic interests of the United States and its allies. In 2019, General David Berger, 38th Commandant of the Marine Corps (CMC), was explicit in his language and unsparing in his assessment of the United States Marine Corps' (USMC) readiness for future conflict, stating that "the Marine Corps is not organized, trained, or equipped to support the naval force – operating in contested maritime spaces, facilitating sea control, or executing distributed maritime operations" and demanded that the organization find a way to answer the question "What does the Marine Corps provide the United States Navy (USN) and the Joint Force?" (Berger 2019, p. 2) Answering the challenge of its commandant, the USMC is in the midst of a fundamental shift in its organizational priorities with the end state of being manned, trained, and equipped to facilitate better integration with the USN and Joint Force and to execute Expeditionary Advanced Base Operations (EABO) and Littoral Operations in a Contested Environment (LOCE) in the Indo-Pacific Command (INDOPACOM) area of operations.

Transitioning to a force that can conduct EABO and LOCE requires the Marine Corps to procure new combat systems and to develop new procedures, techniques, and tactics (PTTs) to gain and maintain lethality in geographically remote locations. Rather than rely on exquisite and expensive platforms, the Marine Corps will need to pursue "affordable and plentiful" yet lethal platforms in the form of unmanned or lightly manned autonomous and semi-autonomous surface vessels (Berger 2019, p. 4). Acting as a reconnaissance and counter-reconnaissance force as part of a defense in depth in the littorals of the Western Pacific Ocean built around the Marine Littoral Regiment (MLR), these vessels can greatly increase the lethality of a cohesive Navy-Marine Corps force and can impose a great cost on our adversaries in a future conflict.

In keeping with the CMC's number one priority of force design, this research seeks to use combat modeling and simulation as a cost-effective approach to conduct extensive experimentation and analysis to inform decisions regarding the capabilities and employment of relatively inexpensive yet lethal autonomous and semi-autonomous platforms. The data generated by our combat modeling will enable a robust analysis of critical factors regarding the characteristics and employment of weapon systems and the accompanying development of new PTTs which will be necessary in the future fight.

A. DEFINING THE PROBLEM

1. Mission Essential Tasks

The *Tentative Manual for Expeditionary Advanced Base Operations* (TM EABO 2021) defines EABO as "a form of expeditionary warfare that involves the employment of mobile, low-signature, persistent, and relatively easy to maintain and sustain naval expeditionary forces from a series of austere, temporary locations ashore or inshore within a contested or potentially contested maritime area in order to conduct sea denial, support sea control, or enable fleet sustainment" (TM EABO 2021, p. 1-3). LOCE "is a concept that describes the integrated application of Navy and Marine Corps capabilities to overcome emerging threats within littoral areas that are rapidly expanding in operational depth, complexity, and lethality" (USMC 2021).

2. USMC's Role in EABO and LOCE

The *38th Commandant's Planning Guidance* (CPG) asserts that the USMC lacks the assets and capabilities to persist in a contested environment. This begs the question: what, then, *is* the mission or role of the USMC in the future operating environment? A conflict with the PRC will feature none of the relatively safe and secure forward operating bases (FOBs) of Operation Enduring Freedom (OEF) or Operation Iraqi Freedom (OIF). Nor will it feature guaranteed access to a secure Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) network with omnipresent unmanned aerial vehicles (UAVs) feeding live footage of enemy actions directly to the warfighter. Rather, the USMC should expect to be responsible for the mission of conducting reconnaissance and counter-reconnaissance for not only itself, but also for the joint force by conducting "sea denial operations using organic sensors and weapons systems to complete kill webs, but also by integrating organic capabilities with naval and joint all-domain capabilities" (A Concept for Stand-In Forces 2021, p. 4).

The actions described above will occur in what the 2018 National Defense Strategy (NDS) defines as the contact and blunt layers of the Global Operating Model. The contact layer is where competition below the level of armed conflict occurs (i.e., deterrence, theater security cooperation (TSC) exercises, etc.). In the blunt layer, friendly forces delay, degrade, or deny adversary aggression (NDS 2018).

Figure 1, taken from the TM EABO, depicts some conceptual battlefield geometries. The reader should note the stand-in force operating well within the weapon engagement zone (WEZ) of an adversary, highlighting the importance of survivability as a critical attribute of the MLR.

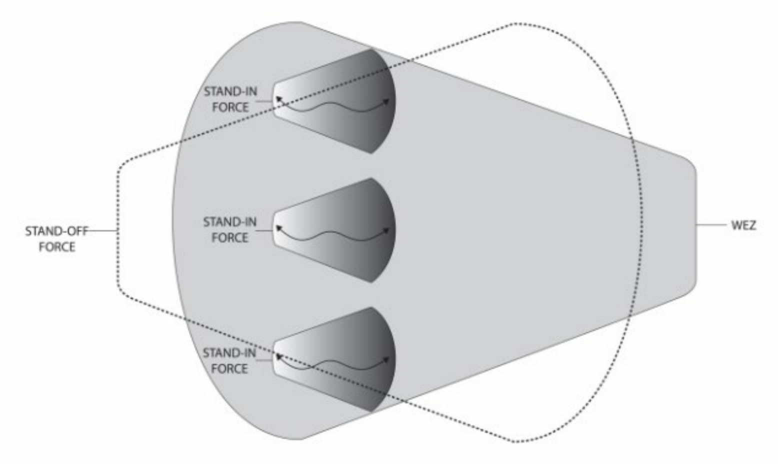

Figure 1. Conceptual battlespace geometries showing stand-in force positioning. Source: USMC (2021).

The CMC envisions the USMC fulfilling the role of a “stand-in force” (SIF) in the both the contact and blunt layers. Stand-in forces are “small but lethal, low signature, mobile, relatively simple to maintain and sustain forces designed to operate across the competition continuum within a contested area as the leading edge of a maritime defense in depth in order to intentionally disrupt the plans of a potential or actual adversary” (A Concept for Stand-In Forces 2021). Winning for the SIF looks like presenting a credible threat to PRC operations which cannot be ignored, and should the PRC choose to attack the SIF, imposing a prohibitively high operational cost on the enemy (A Concept for Stand-In Forces 2021).

Unfortunately, the USMC lacks the organic reconnaissance platforms and capability required to conduct reconnaissance and counter-reconnaissance in the maritime domain. The primary reconnaissance assets organic to a USMC infantry regiment are the Scout Sniper Platoon (SSP) and Small Unmanned Aerial Systems (SUAS) such as the Raven and Puma, all of which are woefully inadequate for collecting information in the littorals. These platforms are limited in the range, sensors, and endurance necessary to ascertain the location, composition, and disposition of People’s Liberation Army Navy (PLAN) surface forces accurately and quickly enough for the USMC to dictate the terms of an engagement. The dearth of adequate reconnaissance and counter-reconnaissance assets raises a few critical questions which the USMC must answer:

- What platforms or capabilities are we lacking?
- What are the characteristics or capabilities required of new platforms?
- How many need to be purchased?
- How do we employ the assets?

B. FINDING A WAY TO WIN

If the USMC wishes to be a contributing member the joint force ahead of and during a future conflict with the PRC, it needs to become the premier reconnaissance and counter-reconnaissance force in the Department of Defense (DOD). This role looks very different in a maritime environment than in a terrestrial environment. To become and remain a legitimate threat to PLAN operations, the MLR needs to leverage joint assets as part of the guard force, capable of conducting sustained security operations in a contested environment, in a defense in depth. Security operations, as defined in Marine Corps Doctrinal Publication (MCDP) 1–0 *Operations*, are an integral part of any operation, and can be offensive operations conducted in the MLR's deep area (also known as the "security area;" see Figure 2) "to intercept, engage, delay, or disorganize the enemy" (USMC 2017, p. 6–4).

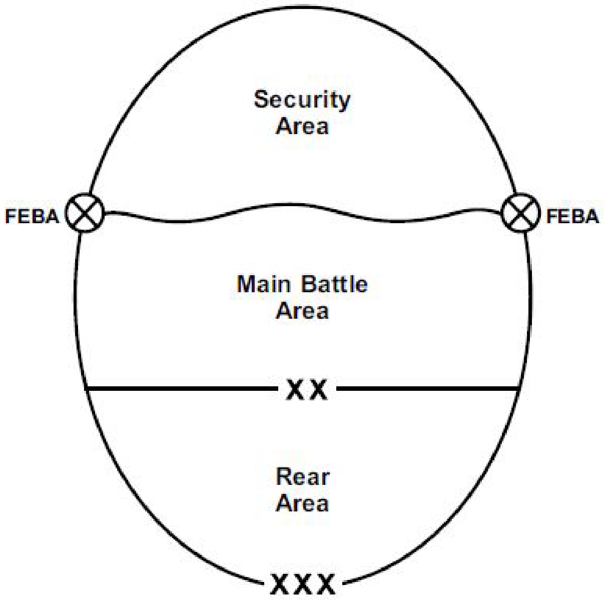

Figure 2. Doctrinal organization of a defense's battlespace. Source: USMC (2019).

A guard force's mission "is to protect the main force from attack, direct fire, and observation by fighting to gain time, while also observing and reporting information" (USMC 2017, p. 11–13). The author proposes that the MLR's guard force will consist of flotillas of lightly manned and unmanned surface vessels, which, in effect, will extend the MLR's lethality deeper into the contested zone and allow friendly forces to detect and target enemy ships before being targeted themselves. The desired end state for the employment of an integrated USN-USMC guard force is enhanced friendly lethality and increased survivability of manned, land-based platforms and formations.

This research will analyze the effectiveness of three platforms that will comprise the guard force: the Lightly Manned Autonomous Combat Capability (LMACC), the Medium Unmanned Surface Vessel (MUSV), and the Long-Range Unmanned Surface Vessel (LRUSV). Figures 3, 4, and 5 depict the LMACC, MUSV, and LRUSV, respectively.

1. Lightly Manned Autonomous Combat Capability (LMACC)

- Displacement: ~ 600 tons
- Length: 214 feet
- Beam: 32 feet
- Draft: 6.5 feet
- Speed: 30 knots
- Range: 7500+ nautical miles
- Propulsion: 2x steerable, reversible pump jets
- Crew: 15
- Armament: 8x Long Range Anti-ship Missile (LRASM); 36x Spike Non-line of sight (NLOS) missile; 7x pintle-mounted Javelin command launch units; 105mm howitzer; SeaRam air defense system
- Sensors: AN/SLQ-32 electronic warfare (EW) suite; commercial surface search radar; mission specific intelligence and sensor packages

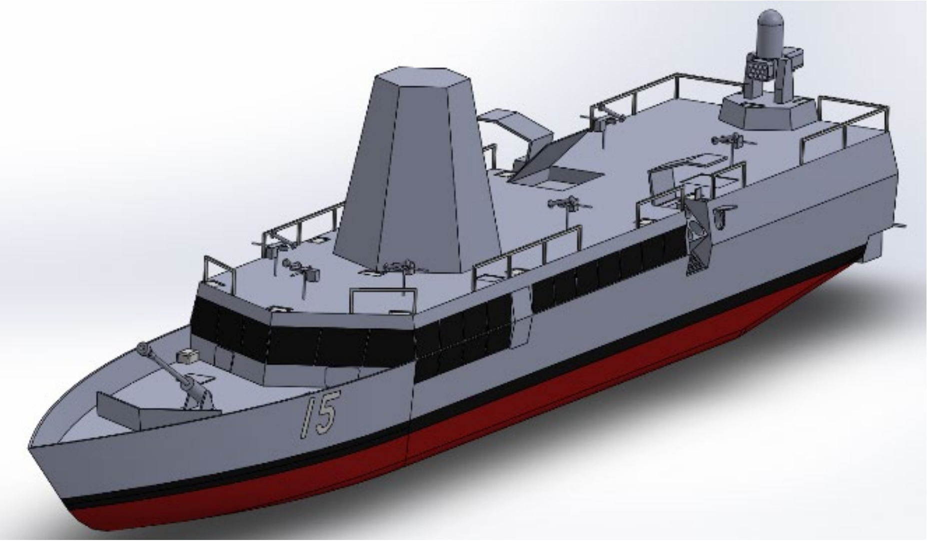

Figure 3. Artist's rendering of the LMACC. Source: Prof. Shelley Gallup (2021).

2. Medium Unmanned Surface Vessel (MUSV)

- Displacement: TBD
- Length: 195 feet
- Beam: TBD
- Draft: TBD
- Speed: 10–15 knots (cruise); 24 knots (max)
- Range: 4500 nm
- Armament: TBD
- Sensors: various EW packages; passive electronic collection packages; mission specific surface and subsurface sensors

Figure 4. Artist's rendering of a potential MUSV design. Source: l3harris.com (2020).

3. Long Range Unmanned Surface Vessel (LRUSV)

- Displacement: TBD
- Length: 11m
- Beam: TBD
- Draft: TBD
- Speed: 10–15 knots (cruise); 40 knots (max)
- Range: TBD
- Armament: organic precision fires (OPF) loitering munitions
- Sensors: various EW packages; passive electronic collection packages

Figure 5. Artist's rendering of a LRUSV design. Source: navalnews.com (2021).

C. SCOPE

This research focuses on modeling, analyzing, and assessing the combat and engagements occurring *from the littorals* into the open sea, rather than an amphibious assault or land combat *into the littorals*. In support of this focus, this research will address the following questions:

- Does integrating a guard force of autonomous and semi-autonomous vessels into the Marine Littoral Regiment's defense in depth increase the lethality and survivability of friendly land-based units? Additionally, what friendly and enemy factors contribute to the survivability of the guard force?

- Can the use of autonomous and semi-autonomous vessels to detect and strike an enemy surface force as part of an MLR increase its ability to attrite enemy ships?

- Which factors of the guard force have the most impact on the MLR's ability to detect, report, and engage an enemy surface force before the enemy force can detect and engage land-based friendly units?

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II. STRATEGIC CONTEXT AND KEY OPERATIONAL PRINCIPLES AND CONCEPTS

> In day-to-day activity, SIF deter potential adversaries by establishing the forward edge of a partnered maritime defense in depth that denies the adversary freedom of action.
>
> —Gen. David Berger, 38th CMC

The purpose of this chapter is to establish a common understanding of the geopolitical conditions in the Western Pacific and to familiarize the reader with the doctrinal concepts of defense in depth, reconnaissance and counter-reconnaissance, and security operations. These doctrinal concepts form the basis for the tactical scenario this research will analyze.

A. GEOPOLITICAL CONDITIONS

1. Chinese Strategic Interests and Goals

The PRC has in the past three decades asserted sovereignty over almost the entirety of the South China Sea. Citing historical documents and previous sovereignty claims by the Republic of China, the PRC declares all territory inside of the “nine-dash line,” as seen in Figure 6, to be property of the PRC with complete disregard for international law and the territorial claims of the countries ringing the South China Sea (Bader 2014). From an economic standpoint, the PRC’s claims of sovereignty are an attempt to dominate the competition for natural resources like oil, natural gas, and fishing. Militarily, the PRC seeks to avoid a conflict with the USN on the open ocean. Rather, they seek to exploit the constricted geography of the region to create stand-off from mainland China by creating a contested zone inside the First Island Chain (FIC) using a variety of anti-access, area-denial (A2AD) measures to deny the U.S. and its allies’ freedom of movement in the region. The most public example of the PRC’s attempt to control the territory within the nine-dash line is the expansion of existing islands in the Spratly Islands and the Paracel Islands to accommodate robust, permanent facilities capable of supporting military operations (Sutton 2021).

Figure 6. Identification of the first and second island chains. Source: globalsecurity.org (2022).

2. U.S. Strategic Interests and Goals

Much like the PRC, the U.S. has a long-standing strategic interest in the South China Sea and within the FIC. Economically, the FIC contains territorial claims of seven of 10 members of the Association of Southeast Asian Nations (ASEAN), almost all of whom participate extensively in trade with the U.S. Further, according to the Congressional Research Service, an estimated $3.4 trillion in goods transits the South China Sea every year (Dolven et al. 2021, p. 1). Diplomatically, the Philippines, Japan, and South Korea, all of whom are treaty allies with the U.S. and whose security the U.S. is the guarantor of, comprise the eastern and northern border of the FIC and are confronted daily by the pressure of China's territorial claims. Finally, as the world's foremost naval power, the U.S. has an obligation to enforce international rules and norms governing freedom of navigation in international waters.

The MLR is a critical element of the plan to safeguard the U.S.' strategic interests. As a persistent forward presence in the FIC, the MLR will be a credible military threat and will serve as a deterrent to an adversary's naval operations while also demonstrating the U.S.' commitment to the security of our regional allies and partners (USMC 2021).

B. KEY OPERATIONAL CONCEPTS AND PRINCIPLES

1. Defensive Operations

As General Berger's quote at the beginning of the chapter alludes to, the U.S. is on the strategic defensive in the Western Pacific. However, the term "defense" does not imply passivity or sitting idly by waiting for events to transpire. To the contrary, doctrinal publications emphasize the importance of tactical offensive action to exploit enemy vulnerabilities. MCDP 1-0 defines "defense" as "a coordinated effort by a force to defeat an attack by an opposing force and prevent it from achieving its objectives" (USMC 2019, p. Glossary-12). These tactical offensive measures include active reconnaissance and counter-reconnaissance efforts to determine the enemy's composition and disposition while denying the enemy the ability to gather information on friendly forces; the use of long-range fires to disrupt enemy formations and delay enemy movements; and, if practical, the use of fire and maneuver to seize the initiative from the enemy (USMC 2019). In short, a defense must be *proactive* vice reactive.

The term "maritime defense in depth" is mentioned 11 times in *A Concept for Stand-in Forces*. MCDP 1-0 defines "defense in depth" as "the siting of mutually supporting defensive positions designed to absorb and progressively weaken an attack, prevent initial observation of the whole position by the enemy, and to allow the commander to maneuver the reserve" (USMC 2019, p. Glossary-12). Note that "depth" is described in structural terms rather than prescribed physical distances; the depth of a defense corresponds to the layers comprising it and the capabilities of the layers to defeat an attack. The security area is a critical piece of a defense in depth. A highly capable and resilient force positioned in the security area can deter an enemy from choosing a certain course of action (COA) or can impose a high cost in terms of casualties or loss of operational tempo if the enemy chooses to fight its way through the security area.

As illustrated by Figure 7 , the battlespace is divided into three main areas: the deep, or "security," area; the main battle area; and the rear area. For the purposes of this research, the security area is inside the FIC and is where SIF will operate.

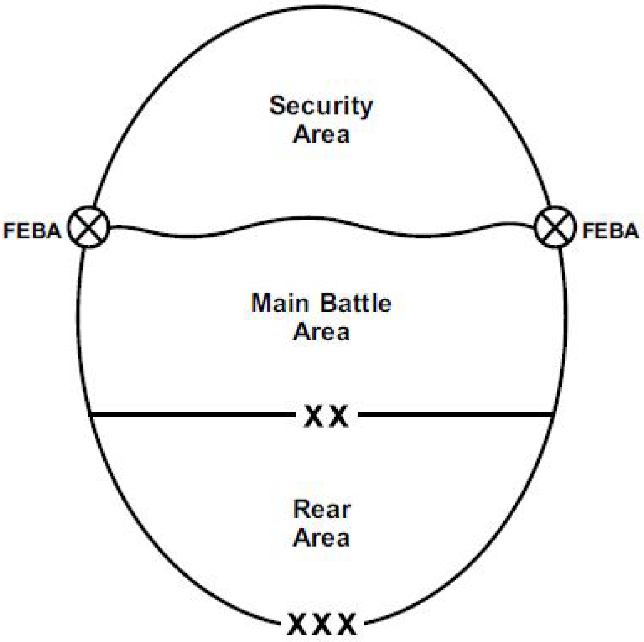

Figure 7. Doctrinal organization of a defense's battlespace. Source: USMC (2019).

Inside the security area, friendly forces execute one of three main tactical tasks: screen, guard, or cover. Collectively, these three tasks are known as "security operations." While each of these tasks has its own unique definition, they share a common theme of seeking to "gather, gain, and maintain contact" with the enemy (USMC 2019, p. 8-2). Security operations encompasses the actions of reconnaissance and counter-reconnaissance. Reconnaissance is inherent to the three tactical tasks identified previously. The information gathered in the security area through reconnaissance is crucial in that it enhances a commander's understanding of the enemy's intentions and facilitates informed decisions regarding the orientation and actions of friendly forces in response to a threat. In order to take decisive action to exploit a weakness, a commander must know the weakness exists in the first place.

Understanding the importance of reconnaissance to friendly operations, a commander should naturally emphasize counter-reconnaissance operations in the security area as a way of limiting the enemy's ability to make informed decisions. Counter-reconnaissance is "all measures taken to prevent hostile observation of a force, area, or place" and are an active, offensive component of any lethal defense in depth (USMC 2019, p. Glossary-10). The payoff of counter-reconnaissance operations is two-fold: 1) Degrading the enemy's situational awareness increases uncertainty and risk for the enemy commander; 2) engaging, or simply observing, the enemy in a certain area may confirm or deny the friendly commander's assumptions about the enemy's intentions.

2. Application of Defensive Principles in a Maritime Defense in Depth

a. Adapting Terrestrial Doctrine for a Maritime Environment

In the Marine Corps, doctrine is treated less like a rigidly adhered-to recipe and more like a foundation for a common understanding of how the Marine Corps fights. As such, there is very little fundamental difference between a defense executed on land and a defense executed in the littorals. A commander must still contribute a great deal of energy and combat power to reconnaissance and counter-reconnaissance in the deep area if he wishes to remain informed about the enemy's intentions and shape the fight. A commander must still exploit advantages afforded by favorable terrain; maintain a high degree of tactical flexibility to counter an unexpected enemy action; and create depth using scouts, manned and unmanned listening posts, and security patrols. There are fundamental differences between a defense in a land campaign and a defense in a maritime campaign, too. For instance, in a maritime defense the defender is quite literally on an island, which simplifies the reconnaissance problem for the enemy. However, most differences are procedural or methodological in nature.

b. The Marine Littoral Regiment: Structure and Purpose

The MLR is the formation being stood up by the USMC to be the service's contribution to a larger naval campaign in the littorals of the Western Pacific. The MLR is task organized to persist and compete within the WEZ of an adversary and to conduct sea-denial operations through the following mission essential tasks: surveillance and reconnaissance; screen/guard/cover; and surface warfare operations (USMC 2021). The mission essential tasks listed above are not exhaustive but are representative of the types of operations that will be examined in this study.

As illustrated in Figure 8, the MLR is composed of a headquarters/fire element with ground-based anti-ship missile capability; a littoral combat team (LCT) comprising an infantry battalion with anti-ship missiles for fire support; a littoral logistics battalion (LLB), which will provide tactical-level logistical support to the MLR's EABs; and a littoral anti-air battalion (LAAB) composed of an air defense battery, air traffic control specialists, aviation ground support assets, and aviation logistics units.

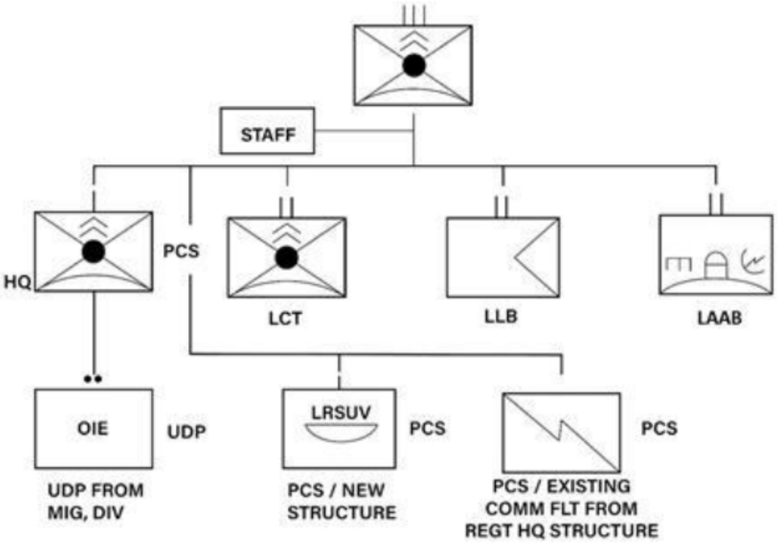

Figure 8. Doctrinal organization of the MLR. Source: USMC (2019).

Of note in Figure 8 is the LRUSV company. This formation is of particular interest because it is the only long-range, persistent reconnaissance asset available to the MLR. The 15 LRUSVs in the MLR will be expected to reconnoiter hundreds, if not thousands, of square miles of the maritime environment while simultaneously executing the tactical tasks of screen, guard, and cover for the MLR. When accounting for attrition and the rotation of assets back to rear areas for maintenance or refit, the MLR's LRUSV company is wholly inadequate for their expected task.

c. Fleet Interoperability

EAB operations by the MLR are not standalone operations. TM EABO, the CPG, and the NDS all make it very clear that maritime operations conducted by the USMC will be part of a larger naval campaign. EAB forces are structured to complement fleet operations, and naval forces will sometimes need to lend forces to the USMC to aid in accomplishing a given mission (USMC 2021). Given the dearth of persistent and lethal reconnaissance and counter-reconnaissance assets in the MLR, it is of supreme importance that the USMC and USN work together to build an appropriately layered and equipped defense in depth to 1) deter enemy action, and 2) dictate the terms and tempo of a conflict.

The teaming of LMACCs and MUSVs with an MLR is one way to enhance fleet interoperability. LMACCs and MUSVs operating in wolfpacks akin to the patrol-torpedo (PT) boats of World War II and supporting EABs with reconnaissance, fire support, and logistical support will significantly enhance the USMC's contribution to a naval campaign (Gallup 2021). With the MUSVs acting as scouts for the LMACCs, and the LMACCs acting as forward-positioned sensors and shooters for the MLR, the MLR will have a lethal and capable guard force that is not only a credible deterrent to an adversary's surface combatants but can also "impose high costs" on the enemy as part of a SIF (USMC 2021).

C. PREVIOUS WORK

Prior research around littoral combat is extensive and examines a range of contemporary concerns to include system requirements and capabilities to inform force design; focused analysis on anti-ship missile capabilities and their employment; and an assessment of methods of employment and tactics to determine which factors have the greatest impact on the survivability of friendly forces.

Research by Major Joshua Faucett, USMC, in 2019 used simulated engagements to assess the importance and influence of certain system requirements such as range, lethality, and launcher capacity (Faucett 2019). One of Faucett's recommendations that is most relevant to this research concerns the synchronization and integration of the joint force, specifically the integration of USN and USMC operations. Faucett states that land-based anti-ship missiles (ASM), operated by the USMC, must be complemented by USN surface forces composed of small surface combatants capable of conducting scouting and strike operations forward of the land-based launchers (Faucett 2019).

In 2020, Captain John Howser, USMC, continued to examine the employment of ground-based anti-ship missiles (GBASM) against PLAN surface forces. Howser's research sought to determine the extent to which GBASM capabilities enabled or enhanced existing sea denial capabilities (Howser 2020). He closely studied the correlation between GBASM tactics and methods of engagements with the number of PLAN ships that reached their objectives and found that the massing of fires from GBASM launchers into "kill boxes" was an effective way to overwhelm the defenses of PLAN ships (Howser 2020). This finding is incorporated into the method of engagement for both the land-based and the sea-based anti-ship missile launchers in this study.

Following the work by Faucett and Howser, in 2021 Captain Sam Fitzmaurice conducted a study using simulation software to identify the factors that most affect the survivability and lethality of USMC units ashore. Fitzmaurice identified several procedures and techniques that are easily implemented at the tactical level to enhance the survivability of GBASM units such as establishing multiple launch sites, minimizing the electronic signature of friendly forces by minimizing the amount of time the ground-based search radars are active, and engaging a target at the maximum range of the anti-ship missile (Fitzmaurice 2021). For future work, he recommended experimenting with the employment of autonomous and semi-autonomous platforms to assess their impact in a scouting role on friendly survivability, and to examine the extent to which these platforms can inflict casualties on the enemy (Fitzmaurice 2021).

III. SIMULATION METHODOLOGY AND DESIGN

A. SCENARIO OVERVIEW

The Tentative Manual for Expeditionary Advanced Base Operations details the MLR's mission essential tasks and serves as a doctrinal foundation for the tactical scenario and the composition of the blue force the research team is modeling (USMC 2021). Additionally, the previous research conducted by Howser and Fitzmaurice informed decisions regarding the composition of the enemy forces as well as the methods of employment for friendly GBASM units. As depicted by Figure 9, the geographic location of the scenario is the west SCS and the island of Palawan and its environs.

Figure 9. Scenario area of operations. Source: Google Earth

The tactical scenario features a PLAN surface action group (SAG) consisting of four major surface combatants and five missile boats against a U.S. force comprised of a GBASM battery, four sections of the Marine Air Defense Integrated System (MADIS), two LMACC flotillas, and one platoon of LRSUVs. The mission of the PLAN SAG is to neutralize the MLR on Palawan to facilitate freedom of maneuver for PLAN forces and to prevent the MLR from interfering with PLAN amphibious operations. The MLR's mission is to control the Mindoro Strait to limit the PLAN's freedom of maneuver in the SCS.

Howser and Fitzmaurice closely examined the performance and tactics of the GBASM agents. Thus, the focus of this research studies the performance of the LMACC, MUSV, and LRUSV and their subsequent impact on the survivability of the MLR's land-based assets. The LMACC flotillas and the LRUSV platoons will be a guard force operating in the MLR's deep area with the intended purpose of inflicting enough casualties on the PLAN SAG that they are forced to withdraw to the northwest back towards their bases in mainland China prior to engaging the MLR's land-based units.

B. MODELING ENVIRONMENT

MAST is an agent-based, stochastic, behavior-based simulation tool for warfare analysis. It is used in this experiment because the user can create various agents with tailored performance parameters and capabilities. An experienced user can create highly accurate agents which model complex, but realistic, behaviors with very little programmer involvement. MAST uses low resolution coding which results in faster run times, allowing for more repetition (Naval Surface Warfare Center [NSWC] Dahlgren Division 2022). MAST has the bonus of being data farmable, meaning through the use of efficiently designed experiments it facilitates exploring many factors (Sanchez 2020). Moreover, with post-processing there is a smooth transition to JMP, R, or other programs for statistical analysis. Finally, MAST allows a user to conduct experimentation on a massive scale with great efficiency. This research simulates 27,200 engagements. Even if all the platforms in the study were fully operational and fielded tomorrow, the money, time, and resources required to conduct live-experimentation on the same level as MAST would be prohibitive.

C. BLUE FORCES

1. GBASM Battery

The GBASM battery is the principal formation within the MLR for providing fires to facilitate fleet operations in key maritime terrain (USMC 2021). GBASM is a general term that will be used throughout this study to describe any land-based anti-ship missile equipped rocket artillery system. The USMC and USN are jointly developing the Navy Marine Expeditionary Ship Interdiction System (NMESIS) which consists of two sub-systems: the Naval Strike Missile (NSM) and the Remotely Operated Ground Unit for Expeditionary (ROGUE) Fires vehicle (Vavasseur 2021). Per Force Design 2030, each MLR will have one NMESIS battery with 18 launchers as part of the MLR table of organization; the NMESIS battery is further subdivided into two platoons of three sections each (USMC 2021). A section is three NMESIS launchers. For the purposes of this study, the GBASM agent assumes all the properties and characteristics of the NMESIS.

The GBASM agent behavior modeled in this study is identical to the behavior modeled by Fitzmaurice. They begin the scenario is a pre-assigned firing position and move to a secondary firing position after either a randomly determined amount of time or after they have fired a missile (Fitzmaurice 2021). The survivability measures of shifting firing positions and staging points were tested by Fitzmaurice and were shown to increase GBASM survivability.

The GBASM agents are networked to all other blue agents and receive their targeting information from the guard force or one of the Ground/Air Task Oriented Radars located at each EAB. They will engage a red surface ship agent once it comes within range of the NSM. The GBASM agent can be detected and targeted by red agents visually before or immediately after a launch, or through detection of the GBASM unit's electronic emissions when communicating with adjacent units (Fitzmaurice 2021).

2. MADIS Section

The MADIS agent represents the MLR's organic air defense platform and there is one MADIS company in the MLR. This study will use four MADIS sections with one section being located at each friendly EAB to provide close-in air defense for the GBASM sections. A MADIS section consists of two vehicles: one vehicle mounts a radar system to detect and track air contacts while the second vehicle is the missile platform. The missile vehicle will begin the scenario in a pre-determined "hide" site and will break cover once an inbound missile is detected; the radar vehicle must remain exposed to operate its radar and will emit radar signals at intermittent intervals. The MADIS section is networked to the other blue agents for situational awareness. Red agents can detect the MADIS section visually or by identifying its electronic signature when it is actively transmitting to other blue agents.

3. LMACC

The LMACC agent is the primary blue force surface combatant and is the manned component of an LMACC flotilla. It is an offensive or defensive platform that is designed to blend into the civilian traffic of the littorals to achieve tactical surprise to sink hostile warships. An LMACC flotilla consists of four LMACCs and five MUSVs; the LMACCs operate in mutually supporting pairs while the MUSVs scout for the LMACCs (Gallup 2021). Each LMACC agent carries eight LRASM as its primary armament and is equipped with the AN/SLQ-32 EW suite which is a passive system for detecting the electronic emissions from enemy vessels or weapon systems.

The LMACC agent forms the backbone of the guard force that will be the MLR's reconnaissance and counter-reconnaissance effort. As illustrated in Figure 10, the LMACC serves as the primary shooter and reconnaissance platform for the scenario. The LMACC is responsible for controlling the MUSVs in its flotilla and serves as a network node for the blue force.

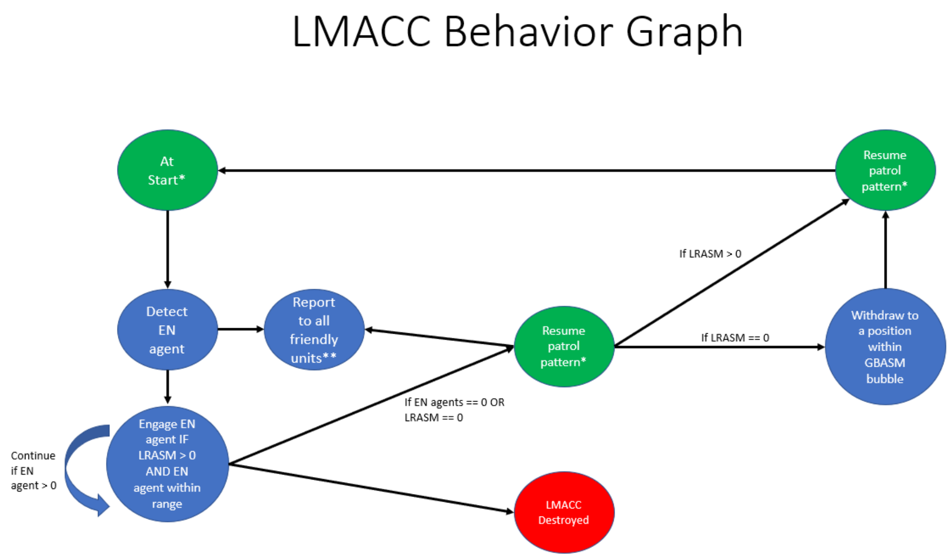
LMACC Behavior Graph

Figure 10. Behavior graph for the LMACC

The LMACC agent will begin the scenario in a pre-determined patrol box. Upon detecting an enemy agent, the LMACC will report the identity and location of the enemy agent to all blue agents in the scenario. On its own, the LMACC can detect enemy agents via its surface search radar or its electronic surveillance system the AN/SLQ-32, but the MUSV and LRUSV are truly the LMACC's eyes and ears. Once the enemy agent is within range, the LMACC agent will coordinate with the other LMACCs in its flotilla to concentrate fires on the enemy agents. Once the enemy agent is destroyed, the LMACC will resume its patrol pattern and continue to scout for enemy agents.

The red force can detect the LMACC visually or by its electronic signature, and the loss of two LMACCs constitutes the withdrawal criterion for the LMACC flotilla.

4. MUSV

The MUSV is the unmanned component of the LMACC flotilla. For the purposes of this research, the MUSV serves as a reconnaissance platform that pushes ahead of the LMACC in search of enemy agents (Gallup 2021). The MUSV is equipped with a passive sensor for detecting the electronic signature of an enemy agent and an electro-optical/infrared camera system for visually acquiring and classifying contacts. While unarmed, the

MUSV is nonetheless a critical component of the MLR guard force because when teamed with a LMACC, a MUSV can significantly expand the reconnaissance web of the MLR and enhances the MLR commander's understanding of the enemy situation in his security area (Gallup 2021).

The MUSV's behavior graph is similar to the LMACC's regarding reconnaissance and reporting. The destruction of two MUSVs constitutes the withdrawal criterion for the flotilla. Red agents can detect the MUSV using their surface search radar but cannot detect the MUSV via emissions detection because the MUSV only uses passive sensors in this scenario.

5. LRUSV

The LRUSV is the platform identified in Force Design 2030 which will be the MLR's organic surface reconnaissance platform. Each MLR is assigned a LRUSV company with 15 LRUSVs (USMC 2021). Fitzmaurice deployed LRUSVs armed with loitering munitions in his research into a picket line between his red SAG and his blue land-based forces (Fitzmaurice 2021). This study expands upon Fitzmaurice's research by incorporating the LRUSV into the MLR guard force's web of sensors. Much like the MUSV, the LRUSV will serve as a scout for the LMACC flotilla. Additionally, this research will feature a design point where the LRUSV is employed much closer to shore as more of a local security asset for the blue land-based forces.

The LRUSV will have the ability to engage red agents using loitering munitions. Loitering munitions, also known as organic precision fires (OPF), are small drones armed with an explosive warhead. They can be operated by a human operator or can detect and engage targets autonomously. While the warhead on a loitering munition is not large enough to sink a red surface combatant, a swarm of loitering munitions can destroy the sensors on a red agent rendering it combat ineffective.

D. RED FORCES

1. Type 055 Renhai Class Guided Missile Destroyer

The Type 055 Renhai agent is the “capital ship” of the PLAN SAG. It is a multi-mission platform capable of performing air defense and anti-surface warfare and is the primary command and control node for the adversary SAG. It is equipped with an electronically scanned air and surface search radar, sensors which detect the electronic emissions of blue agents, the HHQ-9 surface-to-air missile, and CJ-10 and YJ-18 surface-to-surface missiles (Janes 2021).

The Type 055 can detect blue agents using its radar or its electronic sensors. All the red agents are networked into a web of sensors and shooters and any red agent can instantaneously share information with the other red agents. Once it detects a blue agent and correctly classifies it as hostile, the Type 055 will transmit the blue agent’s location to the other red agents in the SAG, and all red agents within range of the blue agent will fire at the blue agent. The research team made the decision to have the red SAG disengage and withdraw if one or more Type 055 is destroyed.

2. Type 052D Luyang III Class Guided Missile Destroyer

The Type 052D Luyang III is also a multi-mission surface combatant and is the primary “shooter” for the PLAN SAG. Like the Type 055, the Type 052D’s primary sensor is an electronically scanned air and surface search radar. It is armed with the HHQ-9 surface-to-air missile and the YJ-18 surface-to-surface missile. For EW, the Type 052D has a sensor for detecting the electronic signature of a blue agent (Janes 2021).

The Type 052D agent can detect blue agents using its radar or electronic sensors. Once a blue agent is detected and correctly classified, the Type 052D agent will share the location with its adjacent red agents and will engage the blue agent once it is within range. The research team made the decision to have the PLAN SAG withdraw from an engagement if one or more Type 052D is destroyed.

3. Type 022 Houbei Class Missile Boat

The Type 022 Houbei is a fast attack missile boat that is armed with YJ-18 surface-to-surface missiles. It is not a major surface combatant like the Type 055 or the Type 052D and typically operates in littoral waters. The Type 022 lacks the advanced air and surface search radar of the larger surface combatants and therefore must be fed target information from a more capable red agent. Given their speed and relatively light armament, the Type 022 normally swarms its targets in coordination with other Type 022s to overwhelm the defenses of their intended targets (Janes 2022).

Once the location of a blue agent is received, the Type 022 will rapidly close to firing range of the blue agent and attack in coordination with the other Type 022s. The research team made the decision to have the PLAN SAG withdraw if three or more Type 022s are destroyed.

4. BZK-005 UAV

The BZK-005 "Long Eagle" is a land-based medium-altitude, long-endurance (MALE) UAV that the PLAN will use for long-range reconnaissance. The BZK-005 can detect U.S. forces via optical sensors as well as electronic emissions receivers and will detect, track, and transmit information on U.S. forces to the PLAN surface combatants; in the event of a PLAN attack on a U.S. agent, the BZK-005 can conduct a battle damage assessment. U.S. forces can detect a BZK-005 agent using the G/ATOR system.

E. MODELING ASSUMPTIONS

The research team made the following assumptions when constructing the model:

- An open conflict between the U.S. and PRC is already in progress and therefore all enemy forces are declared hostile. This means that U.S. agents can engage PLAN agents upon detection and vice versa. Secondly, this assumption facilitates modeling a "worst case" scenario while also keeping the agents' decision making relatively simple to decrease computational complexity.

- The research team is not modeling any land combat. History suggests that once an amphibious force is ashore, it is only a matter of time before the defender loses. The research team is more interested in the MLR's ability to execute the task of sea denial, thereby denying the enemy the opportunity to even move an amphibious force into an objective area. It is also assumed that U.S. forces are in position at the start of the conflict.

- The research team is assuming no degradation in the blue force communication networks. The unmanned/lightly manned platforms also serve as network nodes, so assuming the network is fully functional allows us to experiment with and analyze coordination between blue agents.

- Unclassified information for establishing the capabilities and characteristics of the agents can be found in Jane's Defense.

- Probabilities of hit and probabilities of kill for the anti-ship and surface-to-surface missiles are based on historical data.

- Probabilities of hit and probabilities of kill for the Stinger missile are based on studies which detail the effectiveness of earlier generation Stinger missiles.

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IV. DESIGN OF EXPERIMENTS

> We will need to conduct full-scale, empirically-based experimentation of the future force in realistic maritime and littoral terrain. Our experimentation must be deliberate and iterative, informed by both threat developments and technology advancements.
>
> —Gen. David Berger, 38th CMC

A. MEASURES OF EFFECTIVENESS (MOE)

1. Research Question 1

The study's first research question, "does integrating a guard force of autonomous and semi-autonomous vessels into the Marine Littoral Regiment's defense in depth increase the lethality and survivability of friendly land-based units," examines the effect a guard force has on the survivability of land-based units. We are less interested in the casualties incurred by the guard force because it is assumed that there will be attrition within the guard force as they find and decisively engage the adversary's fleet *before* the enemy can decisively engage friendly land-based forces. Accordingly, the primary MOE for answering Research Question 1 is the number of friendly land-based units destroyed. Two LMACC "formations" are used: the first formation, "LMACC near," has the LMACCs deployed 10–20 nautical miles offshore of Palawan; in the second formation, "LMACC far," the LMACCs are deployed 50–100 nautical miles offshore. The quantity of land-based friendly casualties will be compared between the two scenarios.

2. Research Question 2

Research Question 2, "can the use of autonomous and semi-autonomous vessels to detect and strike an enemy surface force as part of an MLR increase its ability to attrite enemy ships," assesses the ability of the guard force to destroy enemy ships deep in the MLR's battle space, thereby forcing the enemy fleet to withdraw before decisively engaging land-based friendly forces. The primary MOE for Research Question 2 is the number of enemy ships destroyed by the guard force. A secondary MOE is the time at which the enemy ships are detected. This MOE depends on the friendly formation being used and the range of the sensors on the MUSV.

3. Research Question 3

Research Question 3, "which factors of the guard force have the most impact on the MLR's ability to detect, report, and engage an enemy surface force before the enemy force can detect and engage land-based friendly units," investigates which factors of the guard force have the greatest impact on the MLR's ability to detect, report, and engage enemy vessels. To assess this, the number of enemy ships destroyed is the primary MOE. The quantity of enemy ships destroyed is compared across different friendly formations; the number of enemy ships destroyed by armed LRUSVs; and the number of enemy ships destroyed as the quantity of each friendly platform is varied across design points.

B. FACTORS AND LEVELS

1. Categorical Factors

This research uses the three categorical factors identified in Table 1. The categorical factors influence two important characteristics of the guard force. Arming the LRUSV with a loitering munition gives the guard force an additional offensive capability. Loitering munitions launched by the LRUSV can swarm a target, and while the Switchblade 600 is not large enough to sink a major surface combatant, the exterior sensor of an enemy ship can be destroyed quite easily, resulting in a "mission" or "capability kill." The factors pertaining to the LMACCs seek to determine if shooting earlier yields better friendly outcomes than the LMACCs waiting to coordinate their fires with the GBASM battery while exploring whether it is more beneficial for the LMACCs to concentrate their fires on a smaller number of targets as opposed to spreading their missiles across the enemy formation.

Table 1. Categorical factors

Factor	Levels	Comments
LMACC Employment	Near, Far	Physical distance from Palawan the LMACC is stationed
LMACCs Mass Fires	No, Yes	LMACCs engage targets independently
LRUSV Armed	No, Yes	LRUSV carries Switchblade 600 loitering munition

2. Discrete and Continuous Factors

The factors identified in Table 2 explore the influence of agent quantity and capability on the outcome of the simulated engagements. By varying the quantity of each platform, we are exploring the effects of having more sensors and shooters on the battlefield. Is more necessarily better? If a certain combination of platforms works better than others, these factors can serve as a planning factor for commanders when requesting forces.

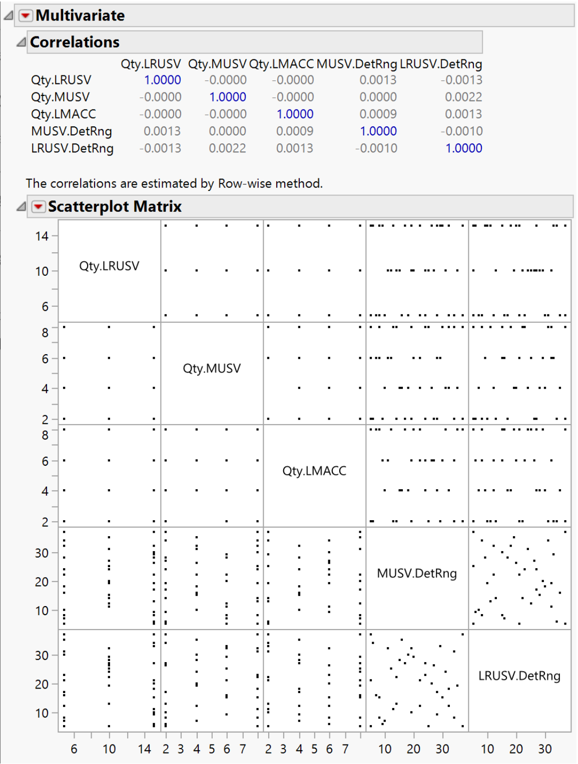
Table 2. Discrete and continuous factors

Factor	Levels	Factor Type	Comments
Quantity LRUSV	10, 15, 20	Discrete	
Quantity MUSV	2, 4, 6, 8	Discrete	
Quantity LMACC	2, 4, 6, 8	Discrete	
MUSV Detection Range	5 to 37	Continuous	Distance in nautical miles to horizon for visual detection
LRSUV Detection Range	5 to 37	Continuous	Distance in nautical miles to horizon for visual detection

In theory, the LRUSV and MUSV will be equipped with electro-optical/infrared sensors to detect and classify contacts visually in addition to employing passive detection methods. Since distance to the visible horizon increases with altitude, this research explores if the LRUSV and MUSV should be equipped with some sort of drone or tethered aerostat to increase its visible detection range. Additionally, this factor explores the effects of the smaller vessels being able to detect enemy ships at greater ranges and determine if there are better friendly outcomes associated with earlier detection.

C. EXPERIMENTAL DESIGN

To examine the effects of the factors listed earlier in the model, a combination of a full factorial design and nearly orthogonal and balanced (NOB) design was used to generate 544 total design points (DP). First, there are eight full factorial design points for the three categorical factors. 36 design points for the discrete and continuous factors were generated using the NOB method and were crossed with eight additional design points using the discrete and continuous factors to fill in the corners of the design. The NOB method was chosen due to its space filling properties as well as its reputation for facilitating robust design (Sanchez and Sanchez 2020). The specific design for this experiment was built using a genetic algorithm that constructs a range of inputs which generate an efficient NOB design (MacCalman 2017). The research team then executed 50 replications of each of the 544 DPs for a total of 27,200 simulated battles. As seen in Figure 11, the maximum absolute pairwise correlation between continuous variables in the experiment design is 0.0022.



Multivariate

Correlations

	Qty.LRUSV	Qty.MUSV	Qty.LMACC	MUSV.DetRng	LRUSV.DetRng
Qty.LRUSV	1.0000	-0.0000	-0.0000	0.0013	-0.0013
Qty.MUSV	-0.0000	1.0000	-0.0000	0.0000	0.0022
Qty.LMACC	-0.0000	-0.0000	1.0000	0.0009	0.0013
MUSV.DetRng	0.0013	0.0000	0.0009	1.0000	-0.0010
LRUSV.DetRng	-0.0013	0.0022	0.0013	-0.0010	1.0000

The correlations are estimated by Row-wise method.

Scatterplot Matrix

Figure 11. Numeric variable pairwise correlation

V. ANALYSIS AND RESULTS

The analysis for this research was conducted in JMP Pro 16 (www.jmp.com). The regressions and partition trees were conducted using point means of the output from each design point. Using the point means for the regressions and partition trees reduces variance in the fitted meta models. However, it should be noted that it is nearly impossible to remove all variance from a combat simulation. Despite there not being a human in the loop for this simulation, agent interactions and behavior will change from run to run and design point to design point. Accordingly, since a "simulation" *simulates* real life, it would be unrealistic to attempt to account for or remove all the variability associated with combat.

A. BASE CASE EXPERIMENT

The research team ran a base case experiment consisting of 50 replications of a single design point for the purposes of establishing a baseline of results against which we could compare the results of the full experiment. This also allows us to estimate the variability within a DP. The base case experiment evaluated the lethality and survivability of 36 GBASM launchers with only 15 LRUSVs serving as the guard force. The composition of the enemy SAG was the same as in the full experiment. This engagement represents the MLR fighting with the structure and platforms identified in TM EABO. Table 3 defines the design point for the base case experiment.

Table 3. Base case experiment design points

	Quantity LRUSV	**LRUV Detection Range**	**LRUSV Armed**
DP 1	15	37 nm	No

1. Friendly Survivability Summary Statistics

The results of the base case experiment indicate that a high level of attrition is sustained by friendly forces. In 48 iterations of the experiment, all 15 LRUSVs were destroyed. The median number of GBASM launchers destroyed was 19 and the mean was

18.36. In short, based on the results of the experiment, the friendly commander should plan on 50% of his GBASM launchers being destroyed. Figure 12 is a histogram depicting the distribution of GBASM launchers destroyed in the base case and illustrates the inherent randomness of combat.

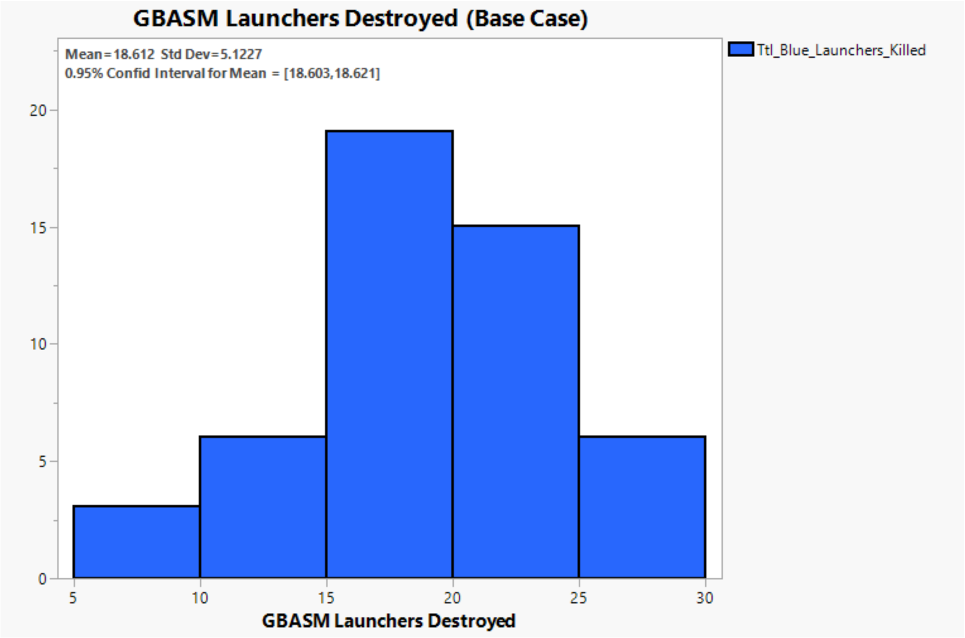
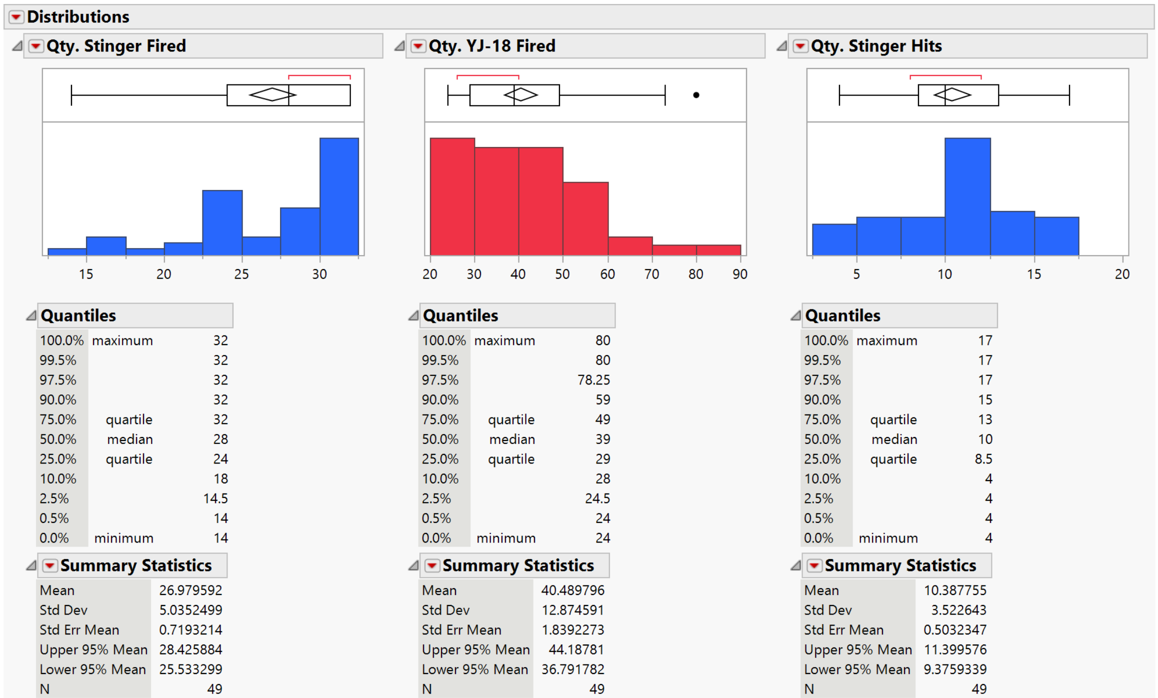


Figure 12. Distribution of GBASM launchers destroyed in the base case experiment

The effectiveness of the friendly defensive capabilities, the MADIS, was also evaluated in the base case as the efficacy of the MLR's organic defensive platforms is a relevant indicator of survivability. The enemy was able to achieve the effects described previously by firing an average of 40.48 land attack missiles. The median number of enemy land attack missiles fired was 39. In response to the enemy missile attack, the MADIS systems in the simulation fired an average of 26.97 Stinger missiles with an average of 10.38 hits for a P(hit) of 38.5%. Figure 13 depicts the distributions across 49 runs (one did not finish) of friendly Stinger missiles fired, enemy land attack missiles fired, and the number of Stinger hits.



Qty. Stinger Fired

Quantiles

100.0%	maximum	32
99.5%		32
97.5%		32
90.0%		32
75.0%	quartile	32
50.0%	median	28
25.0%	quartile	24
10.0%		18
2.5%		14.5
0.5%		14
0.0%	minimum	14

Summary Statistics

Mean	26.979592
Std Dev	5.0352499
Std Err Mean	0.7193214
Upper 95% Mean	28.425884
Lower 95% Mean	25.533299
N	49

Qty. YJ-18 Fired

Quantiles

100.0%	maximum	80
99.5%		80
97.5%		78.25
90.0%		59
75.0%	quartile	49
50.0%	median	39
25.0%	quartile	29
10.0%		28
2.5%		24.5
0.5%		24
0.0%	minimum	24

Summary Statistics

Mean	40.489796
Std Dev	12.874591
Std Err Mean	1.8392273
Upper 95% Mean	44.18781
Lower 95% Mean	36.791782
N	49

Qty. Stinger Hits

Quantiles

100.0%	maximum	17
99.5%		17
97.5%		17
90.0%		15
75.0%	quartile	13
50.0%	median	10
25.0%	quartile	8.5
10.0%		4
2.5%		4
0.5%		4
0.0%	minimum	4

Summary Statistics

Mean	10.387755
Std Dev	3.522643
Std Err Mean	0.5032347
Upper 95% Mean	11.399576
Lower 95% Mean	9.3759339
N	49

Figure 13. Base case experiment missile distribution

2. Survivability Assessment, Conclusions, and Recommendations

Despite an average of roughly 50% of the GBASM launchers being destroyed in the base case experiment, it is the author's assessment that the MLR still retains the *capability* to conduct sea denial or sea control. The MLR's launchers were dispersed across four EABs, and the two northernmost EABs suffer the preponderance of the casualties, therefore the MLR's ability to repel a subsequent enemy attack along the same axis was severely degraded. If the MLR must repel another enemy attack along the same axis as the first, then the MLR needs to redistribute forces from the other EABs. However, forcing the surviving GBASM launchers to break cover and reposition greatly increases the risk that they are detected and targeted by enemy forces.

Friendly survivability is further impacted by the woeful performance of the MLR's organic air defense assets. As indicated by Figure 13, across all 49 runs of the base case the maximum number of missiles fired by the MADIS sections defending the GBASM launchers never exceeds the median number of enemy land attack missiles fired. Even in the seven instances where the number of Stinger missiles fired exceeded the number of enemy YJ-18 missiles fired, we cannot say with confidence that all incoming enemy missiles would be intercepted based on the Stinger P(hit) calculated from the experiment's results.

Based on the results of the base case experiment, until the MLR can field a more effective air defense capability, we recommend that training and operations emphasize the use of signature management, concealment techniques, and the standard operating procedures suggested in Captain Fitzmaurice's research to enhance friendly survivability. Another possible solution to the MLR's air defense deficiency is to leverage joint assets to augment the MLR's air defense plan. These joint assets could include theater air defense assets such as Patriot missile batteries or an Aegis equipped surface combatant.

3. Lethality Summary Statistics

The base case experiment generated outcomes which are surprisingly unfavorable for enemy forces, yet still represent a pyrrhic victory for friendly forces when considering the friendly losses described in the previous section. The mean number of enemy ships destroyed per engagement was 2.63 and the median was 3. Figure 14 shows the overall distribution for enemy ships destroyed.

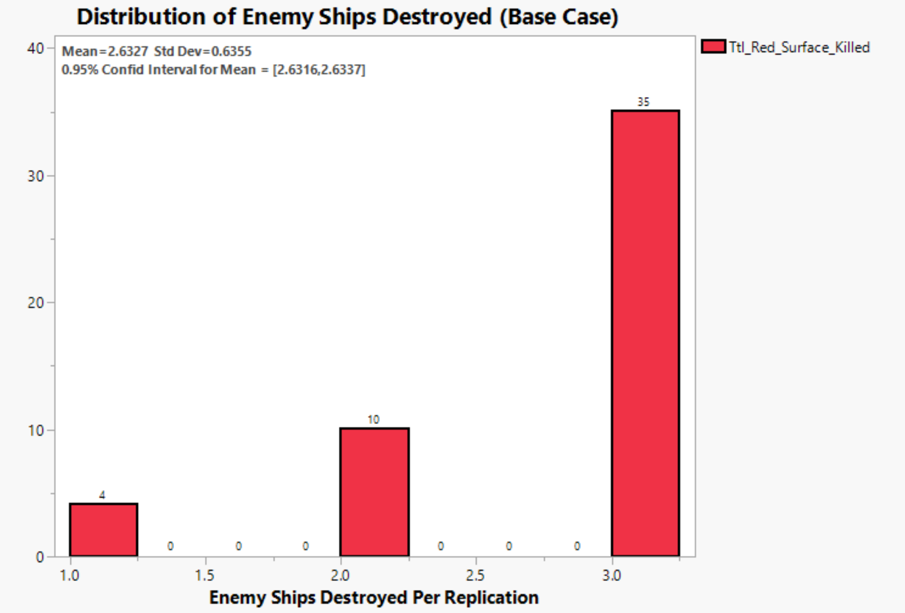
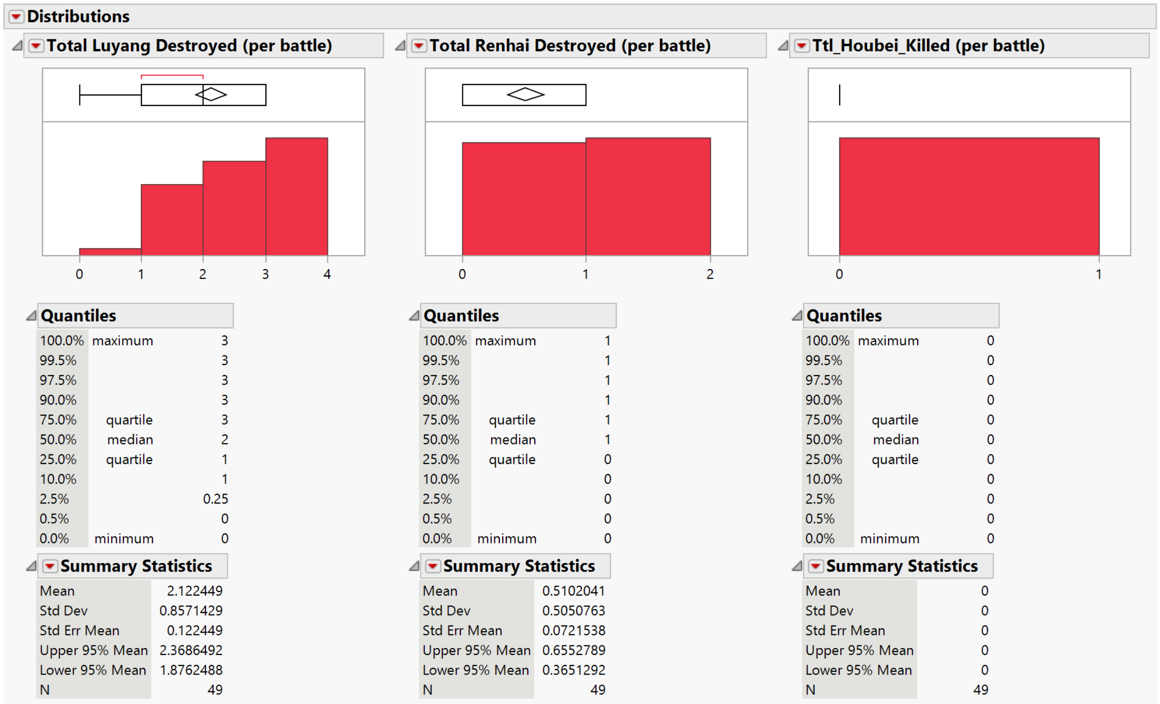


Figure 14. Distribution of enemy ships destroyed in base case experiment

It is very important to highlight the fact that all the enemy ships destroyed during the base case experiment were either the Renhai or the Luyang III. One source of causation for these results is that the LMACC and GBASM are assigned a target precedence which governs their behavior. In the base case, both the LMACC and GBASM target the Renhai first followed by the Luyang III. The frequent destruction of these two ships is significant because these two ship classes are the most capable surface combatants in the whole PLAN, not just in the experiment scenario. In the author's estimation, the destruction of a single ship of either class represents a serious loss for the enemy in terms of capability, power projection, and investment. Figure 15 depicts the distributions of ships destroyed by ship type. Of added significance is the fact that the enemy SAG met its disengagement criteria in all 49 runs. In the histograms of Figure 15 and elsewhere, the bars include all observations on an interval. The interval from three to four, for example, all represent three Luyangs destroyed.



Total Luyang Destroyed (per battle)

Quantiles

100.0%	maximum	3
99.5%		3
97.5%		3
90.0%		3
75.0%	quartile	3
50.0%	median	2
25.0%	quartile	1
10.0%		1
2.5%		0.25
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	2.122449
Std Dev	0.8571429
Std Err Mean	0.122449
Upper 95% Mean	2.3686492
Lower 95% Mean	1.8762488
N	49

Total Renhai Destroyed (per battle)

Quantiles

100.0%	maximum	1
99.5%		1
97.5%		1
90.0%		1
75.0%	quartile	1
50.0%	median	1
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.5102041
Std Dev	0.5050763
Std Err Mean	0.0721538
Upper 95% Mean	0.6552789
Lower 95% Mean	0.3651292
N	49

Ttl_Houbei_Killed (per battle)

Quantiles

100.0%	maximum	0
99.5%		0
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0
Std Dev	0
Std Err Mean	0
Upper 95% Mean	0
Lower 95% Mean	0
N	49

Figure 15. Distribution for enemy ship losses by type in the base case

4. Lethality Assessment, Conclusions, and Recommendations

From the results of the base case experiment, the research team also determined that friendly outcomes in terms of lethality were best when 100–160 NSM were fired. Figure 16 depicts densities of NSM fired versus total Luyang IIIs destroyed and Figure 17 shows NSM fired versus total Renhai destroyed. The darker areas represent higher concentrations of data points where specific quantities of Luyang IIIs and Renhais were destroyed.

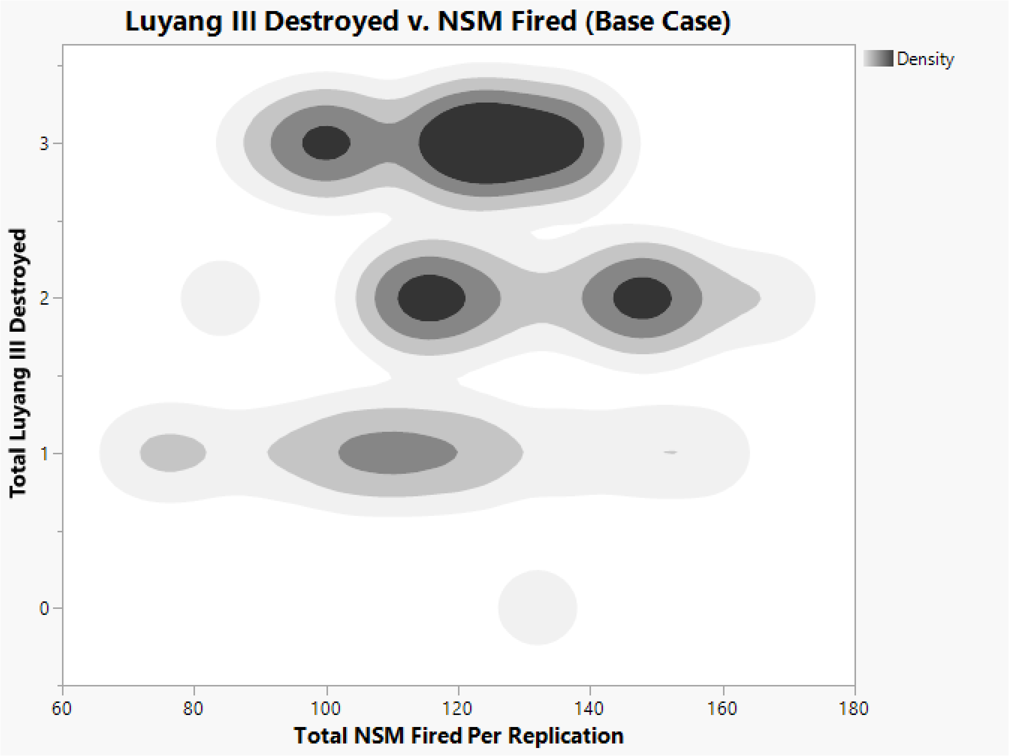


Figure 16. Density plot depicting the relationship between NSM fired and Luyang IIIs destroyed in the base case experiment

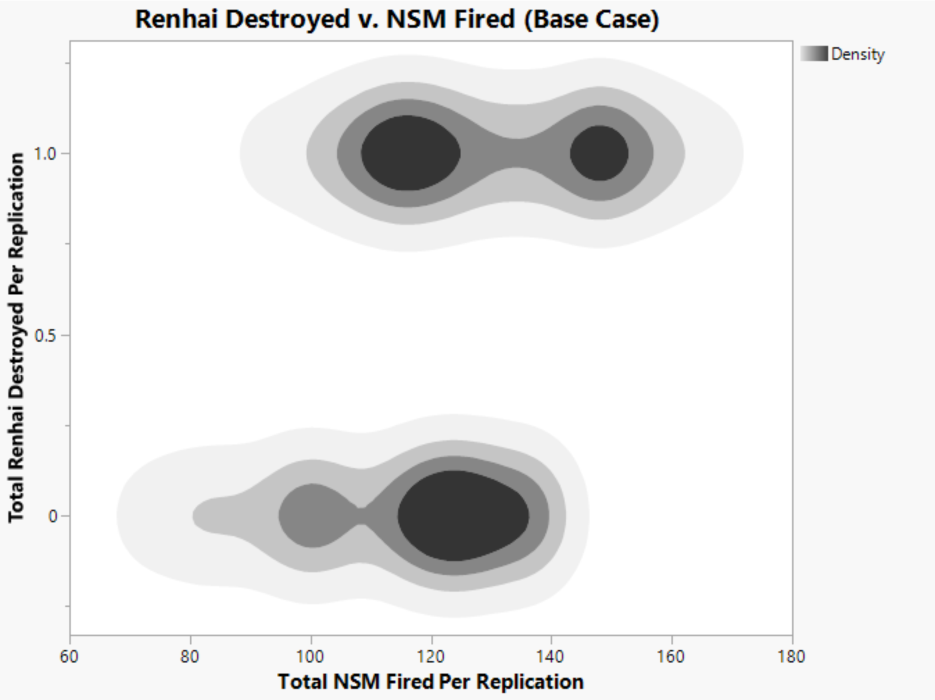


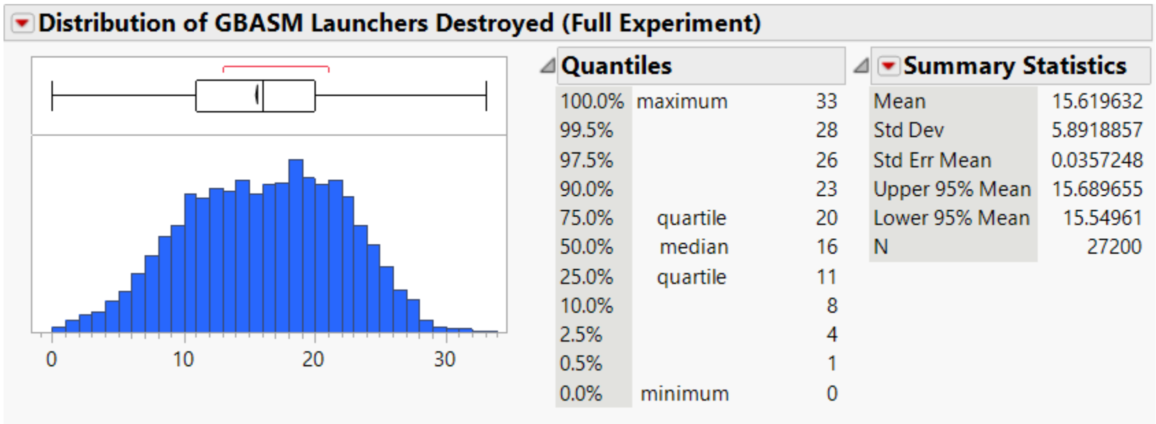
Figure 17. Density plot depicting the relationship between NSM fired and Renhai destroyed in the base case experiment

The research team posits that the MLR can achieve the firing of this quantity of missiles via multiple approaches. One approach is aligned to procurement and includes allocating funding for more launchers in the MLR or designing a launcher that carries more missiles per launcher than the planned NMESIS. Another approach leans more on tactics and includes techniques such as massing fires with multiple GBASM launchers, or massing fires with a different platform working in support of the MLR such as armed scouts, a major surface combatant, or air launched anti-ship cruise missiles.

B. ASSESSING FRIENDLY SURVIVABILITY AND LETHALITY IN THE FULL EXPERIMENT

1. Survivability Summary Statistics

Analysis and conclusions for the full experiment were drawn from the output data generated by 27,200 simulated battles. The research team discovered that there was a marginal *decrease* in the number GBASM launchers destroyed when a guard force was employed as part of a defense in depth. The mean number of GBASM launchers destroyed was 15.61 for the full experiment compared to 18.36 for the base case, and the median number of GBASM launchers destroyed in the full experiment was 16 compared to 19 in the base case. Figure 18 displays the distribution of friendly launchers destroyed over all 27,200 simulated battles.



Distribution of GBASM Launchers Destroyed (Full Experiment)

Quantiles

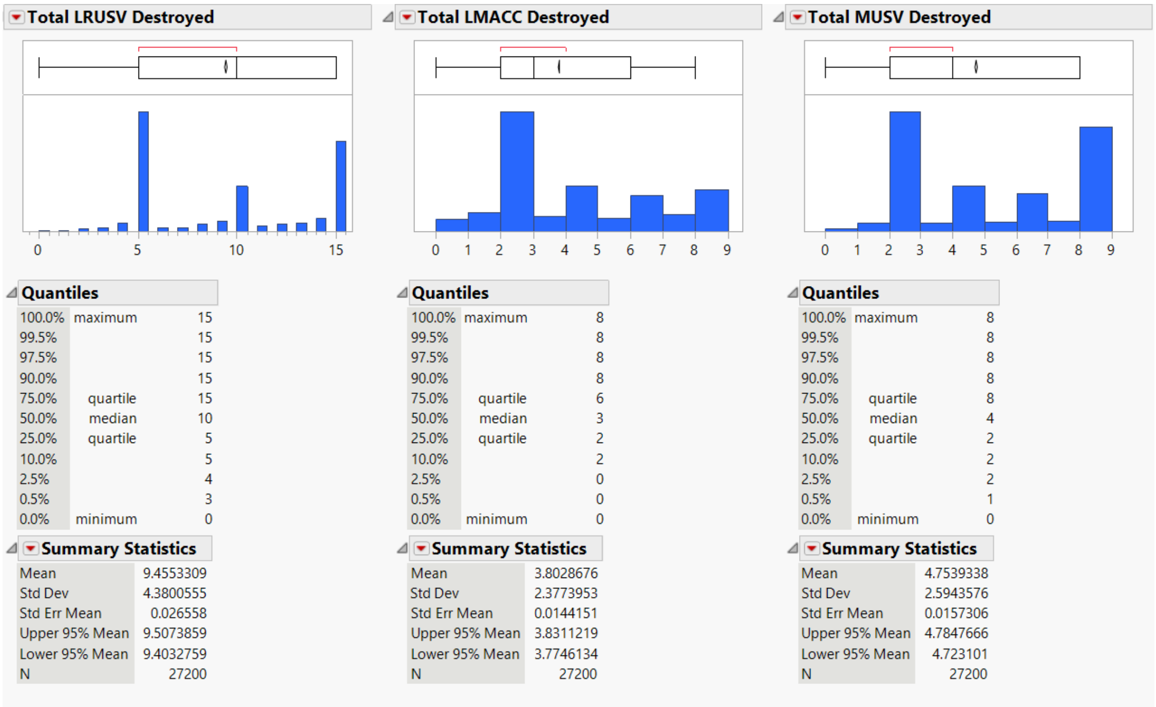
100.0%	maximum	33
99.5%		28
97.5%		26
90.0%		23
75.0%	quartile	20
50.0%	median	16
25.0%	quartile	11
10.0%		8
2.5%		4
0.5%		1
0.0%	minimum	0

Summary Statistics

Mean	15.619632
Std Dev	5.8918857
Std Err Mean	0.0357248
Upper 95% Mean	15.689655
Lower 95% Mean	15.54961
N	27200

Figure 18. Summary statistics for GBASM survivability

Casualties in the guard force were rather high as well. The average number of LMACCs, MUSVs, and LRUSVs destroyed was 3.8, 4.75, and 9.45, respectively. Figure 19 depicts the summary statistics for losses in the guard force. While the raw number of vessels lost is startling, the fact that the MUSV and LRUSV are intended to be unmanned platforms greatly reduces the risk to Marines and Sailors and significantly lessens the loss of human life while still allowing the MLR to provide the joint force with a reconnaissance and counter-reconnaissance capability.



Total LRUSV Destroyed

Quantiles

100.0%	maximum	15
99.5%		15
97.5%		15
90.0%		15
75.0%	quartile	15
50.0%	median	10
25.0%	quartile	5
10.0%		5
2.5%		4
0.5%		3
0.0%	minimum	0

Summary Statistics

Mean	9.4553309
Std Dev	4.3800555
Std Err Mean	0.026558
Upper 95% Mean	9.5073859
Lower 95% Mean	9.4032759
N	27200

Total LMACC Destroyed

Quantiles

100.0%	maximum	8
99.5%		8
97.5%		8
90.0%		8
75.0%	quartile	6
50.0%	median	3
25.0%	quartile	2
10.0%		2
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	3.8028676
Std Dev	2.3773953
Std Err Mean	0.0144151
Upper 95% Mean	3.8311219
Lower 95% Mean	3.7746134
N	27200

Total MUSV Destroyed

Quantiles

100.0%	maximum	8
99.5%		8
97.5%		8
90.0%		8
75.0%	quartile	8
50.0%	median	4
25.0%	quartile	2
10.0%		2
2.5%		2
0.5%		1
0.0%	minimum	0

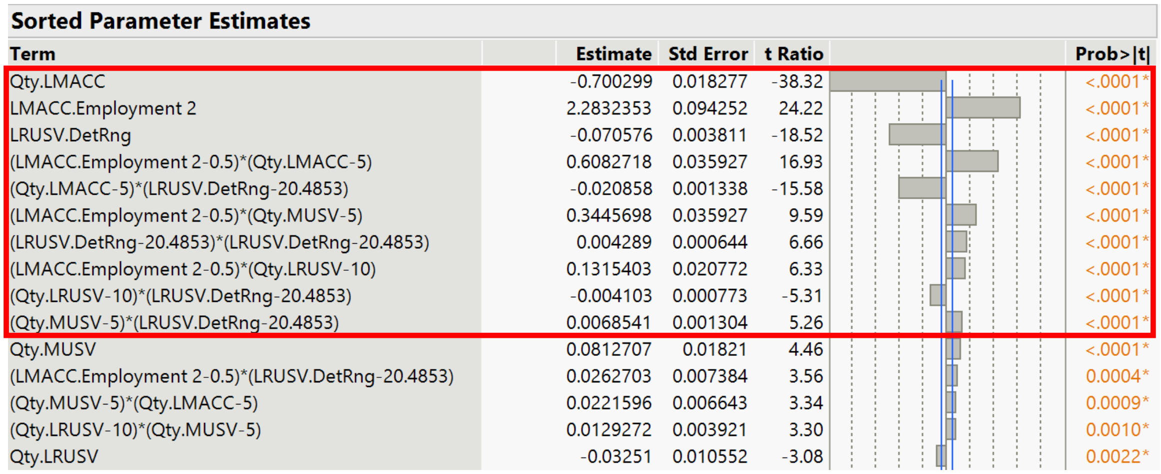
Summary Statistics

Mean	4.7539338
Std Dev	2.5943576
Std Err Mean	0.0157306
Upper 95% Mean	4.7847666
Lower 95% Mean	4.723101
N	27200

Figure 19. Distribution for losses sustained by MLR guard force

2. Survivability Assessment, Conclusions, and Recommendations

The research team conducted a stepwise main effects regression and a least squares regression to determine which factors in the experiment have the most influence on friendly survivability. The stepwise regression selected six of the original eight factors, and a basic linear regression identified LMACC quantity, LMACC employment (i.e., the "near" or "far" template), and LRUSV detection range as the three leading factors in predicting GBASM launcher survival. Another linear regression, with added quadratic and two-way interaction terms, also selected LMACC quantity as the most significant factor. As shown in Figure 20, LMACC quantity is the dominant factor and is nearly twice as significant as the next factor. The red box in Figure 20 stops at the first parameter that is *not* either a top three factor or interaction of a top three factor. The linear regression using quadratic effects has an R^2 value of 0.87.



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Qty.LMACC	-0.700299	0.018277	-38.32	<.0001*
LMACC.Employment 2	2.2832353	0.094252	24.22	<.0001*
LRUSV.DetRng	-0.070576	0.003811	-18.52	<.0001*
(LMACC.Employment 2-0.5)*(Qty.LMACC-5)	0.6082718	0.035927	16.93	<.0001*
(Qty.LMACC-5)*(LRUSV.DetRng-20.4853)	-0.020858	0.001338	-15.58	<.0001*
(LMACC.Employment 2-0.5)*(Qty.MUSV-5)	0.3445698	0.035927	9.59	<.0001*
(LRUSV.DetRng-20.4853)*(LRUSV.DetRng-20.4853)	0.004289	0.000644	6.66	<.0001*
(LMACC.Employment 2-0.5)*(Qty.LRUSV-10)	0.1315403	0.020772	6.33	<.0001*
(Qty.LRUSV-10)*(LRUSV.DetRng-20.4853)	-0.004103	0.000773	-5.31	<.0001*
(Qty.MUSV-5)*(LRUSV.DetRng-20.4853)	0.0068541	0.001304	5.26	<.0001*
Qty.MUSV	0.0812707	0.01821	4.46	<.0001*
(LMACC.Employment 2-0.5)*(LRUSV.DetRng-20.4853)	0.0262703	0.007384	3.56	0.0004*
(Qty.MUSV-5)*(Qty.LMACC-5)	0.0221596	0.006643	3.34	0.0009*
(Qty.LRUSV-10)*(Qty.MUSV-5)	0.0129272	0.003921	3.30	0.0010*
Qty.LRUSV	-0.03251	0.010552	-3.08	0.0022*

Figure 20. Sorted parameter estimates for a linear regression with the number of GBASM launchers destroyed as the response

Another interesting finding, illustrated in Figure 21, is a negative correlation between the mean number of LRASM fired and the mean number of NSM fired. Since the LMACC is the only agent firing the LRASM, if there are more LMACCs in the simulation, then more LRASM will be fired which implies the GBASM launchers can conserve their missiles for future engagement. Since the GBASM launcher must move from their hide site to a firing point to shoot the NSM, it follows that if the GBASM launcher is moving less, then there is a smaller chance it will be detected and targeted by an enemy ship. The cluster of data points around 10 LRASM and 120 NSM is an indication of a situation where the GBASM launchers are overworked and overexposed. The author postulates that more sea-based missiles, dispersed over a wider area, can allow the GBASM launchers to persist for a longer period of time.

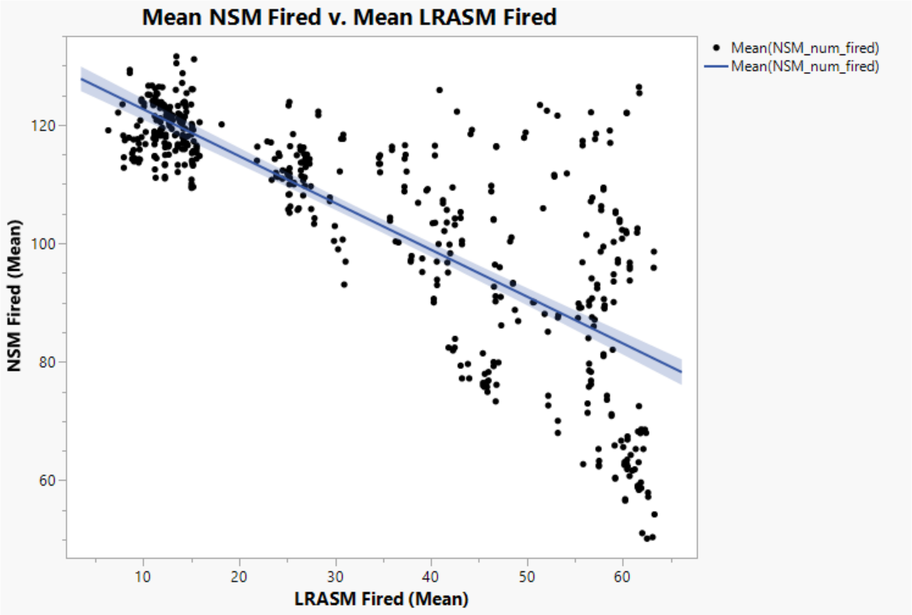


Figure 21. Scatter plot depicting the relationship between LRASM fired and NSM fired

Perhaps because of this relationship between the number of LRASM and NSM fired, there is also a negatively correlated relationship between the number of LRASM fired and the number of GBASM launchers destroyed. Figure 22 shows this relationship. Another interpretation of this relationship is that the LMACC is forcing the enemy SAG to withdraw before the full weight of the enemy's attack can be brought to bear on the GBASM launchers.

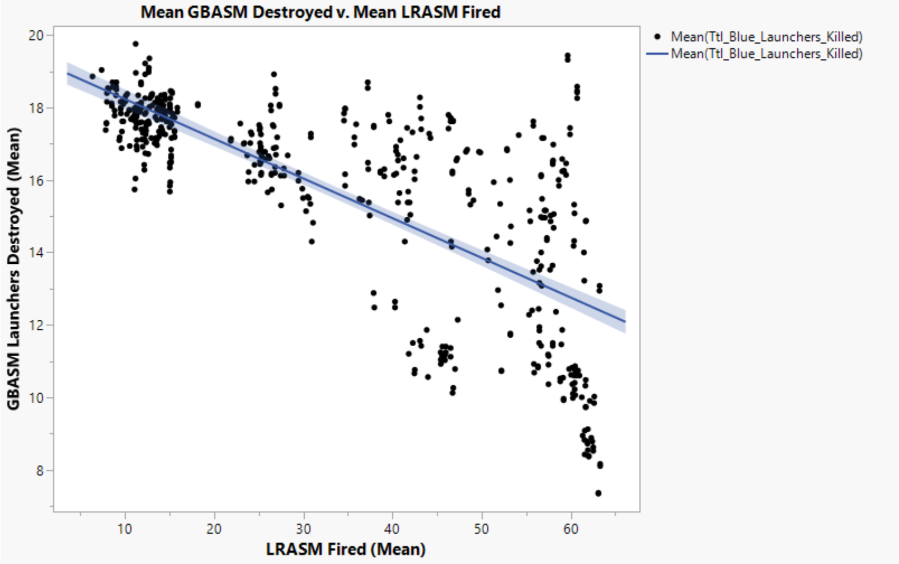


Figure 22. Scatter plot depicting the relationship between LRASM fired and GBASM launchers destroyed

As illustrated in Figure 23, supplementary analysis revealed additional influence of LMACC quantity on the simulation’s results as the mean number of LRASM fired is negatively correlated with the mean number of Stinger missiles fired. It is assessed that a larger number of armed scouts inflicts a higher number of casualties faster on the enemy, which in turn reduces the number of missiles fired by the enemy SAG. There is subsequently a corresponding decrease in the number of Stinger missiles fired to intercept the incoming enemy missiles. This is a very good relationship for the MLR, as analysis from the base case experiment reveals that the MADIS quickly becomes saturated with targets.

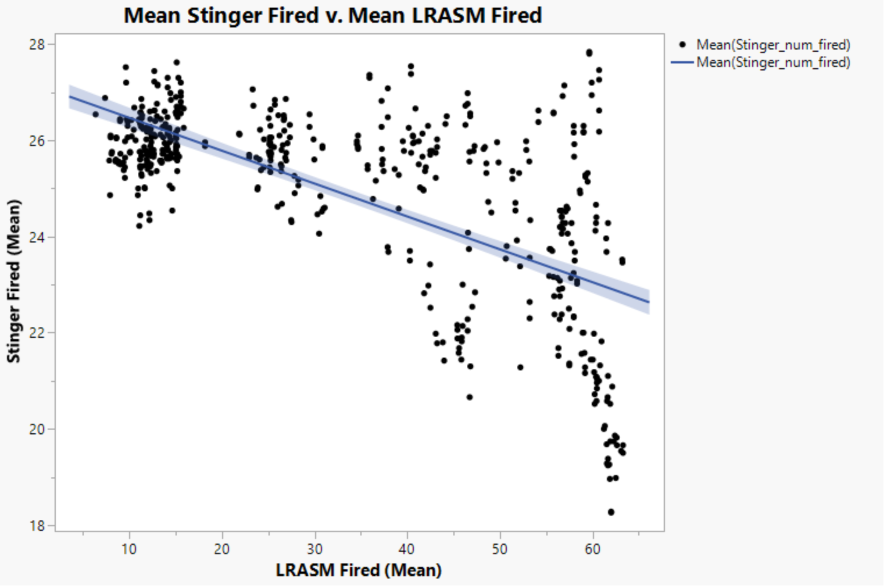


Figure 23. Negative correlation between LRASM fired and Stinger fired

A partition tree analysis of the experiment with GBASM launchers destroyed as the response variable yields some very useful and actionable information. Figure 24 shows a partition tree analysis of four splits resulting in a R^2 of 0.76. Highlighted in green are the critical conditions that predict the best friendly outcomes.

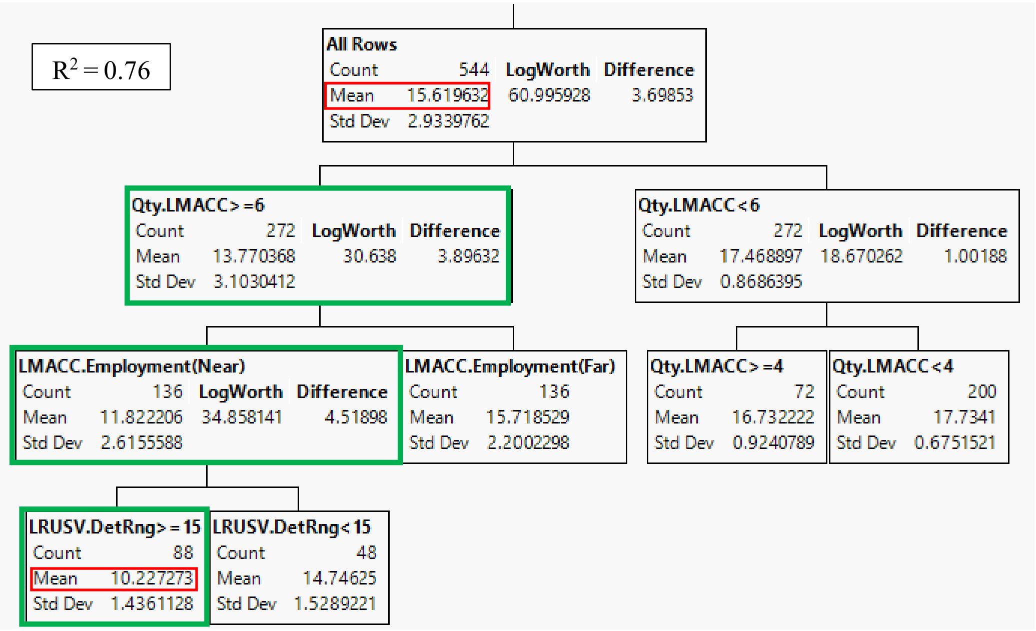


Figure 24. Partition tree analysis of friendly survivability

The string of conditions highlighted in green in Figure 24 underscores the importance pairing scouts with a lethal capability. Of particular importance is that the model predicts a decrease in GBASM launchers from 15.6 to 10.2 if the highlighted conditions are met. This difference represents the survival of a non-trivial number of GBASM launchers and will allow the MLR to persist inside the enemy's WEZ for longer. Furthermore, if the LMACCs are employed close to shore, they need a sensor positioned deep in the battlespace that can detect the enemy as soon as possible. The partition tree suggests 15 nautical miles, however this range could be extended by using a drone, or perhaps a tethered aerostat floated to higher altitude, to boost the range of the LRUSV's sensor.

The partition tree indicates there is an inflection point at six LMACCs in the guard force. In instances where there are six or more LMACCs, the predicted mean value of GBASM launchers destroyed is 13.77 as compared to 17.46 for a guard force employing less than six LMACCs. Additionally, the model predicts that using "LMACC near" (where the LMACCs are approximately 10–15 nm offshore of Palawan) leads to an average of 11.82 GBASM launchers destroyed against an average of 15.71 for the "LMACC far" (100 nm). The box plot in Figure 25 illustrates the distribution of GBASM losses against each LMACC positioning tactic. The box plot confirms a slight, but noticeable, decrease in the number of GBASM launchers destroyed. Of note is the much higher variance in the distribution of losses in the "LMACC near" tactic.

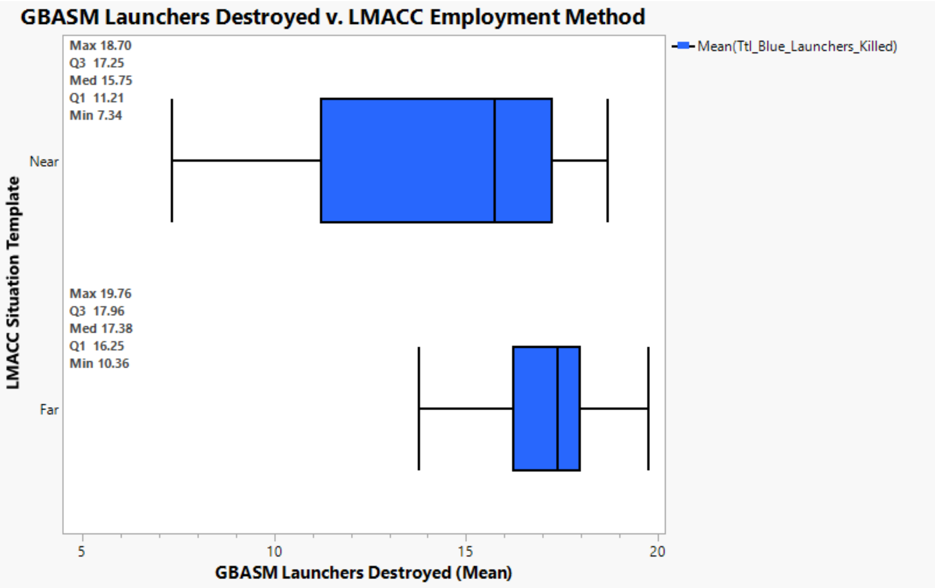


Figure 25. Average number of GBASM launchers destroyed in each LMACC employment method and accompanying distributions

Using the "LMACC near" template also reduced the mean number of LMACCs destroyed in the simulation. This is very significant given the relationship between the number of LRASM fired and other MOEs discussed previously. If the LMACC is employed in a method which increases its life expectancy, then more LRASM can be fired, which should lead to fewer GBASM launchers being destroyed, thus preserving the MLR's organic anti-ship capability. The box plot in Figure 26 shows the distribution of LMACC losses between the two templates.

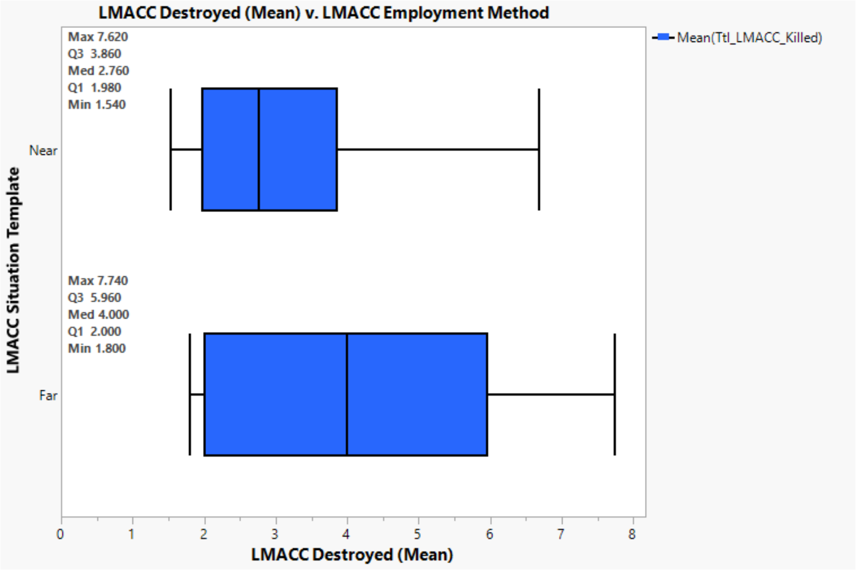


Figure 26. Decreasing LMACC losses in the "Near" tactical template

Interestingly, LMACC positioning had little bearing on the number of MUSVs and LRUSVs destroyed as both averages are similar between the two templates. As indicated in Figure 27, MUSV losses decreased by less than one MUSV, and LRUSV losses increased slightly when comparing the far and near templates.

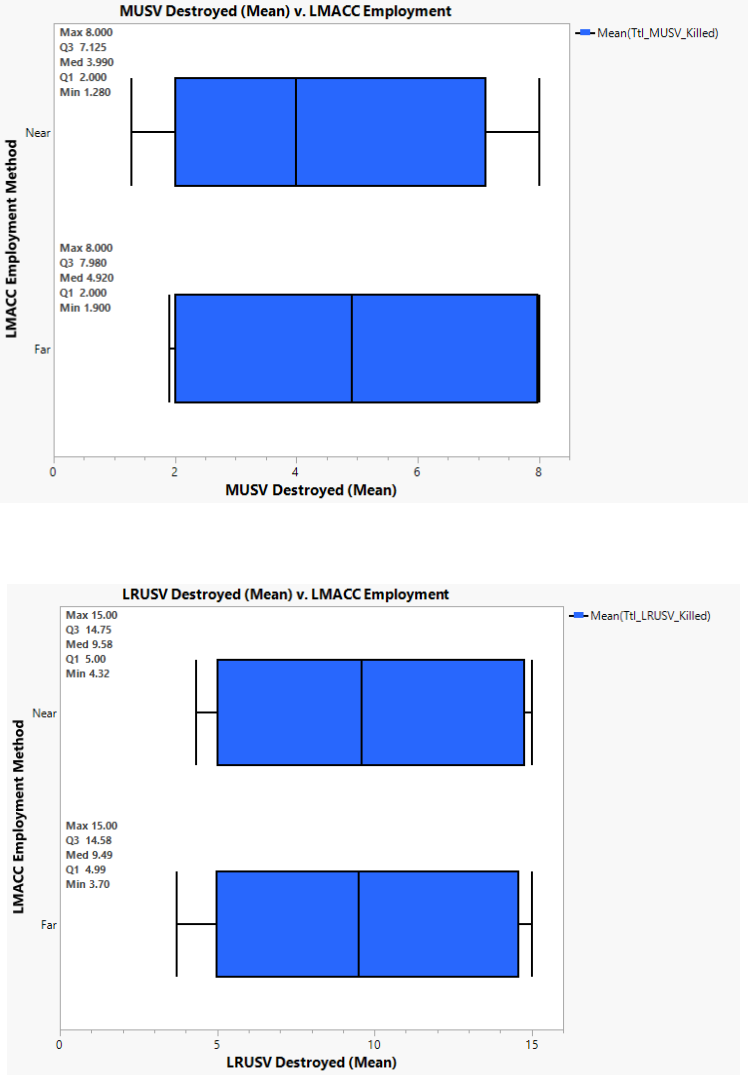


Figure 27. MUSV (top) and LRUSV (bottom) loss comparisons between tactical templates

Based on the output and analysis of the full experiment, the author offers the following assessment of friendly survivability.

First, like the base case, the *capability* to provide sea control or sea denial is preserved, although it is degraded by the loss of approximately half of the GBASM launchers. The surviving GBASM launchers will either need to be repositioned to cover the gaps created by losses, or perhaps a joint asset could be assigned to fulfill the anti-ship mission.

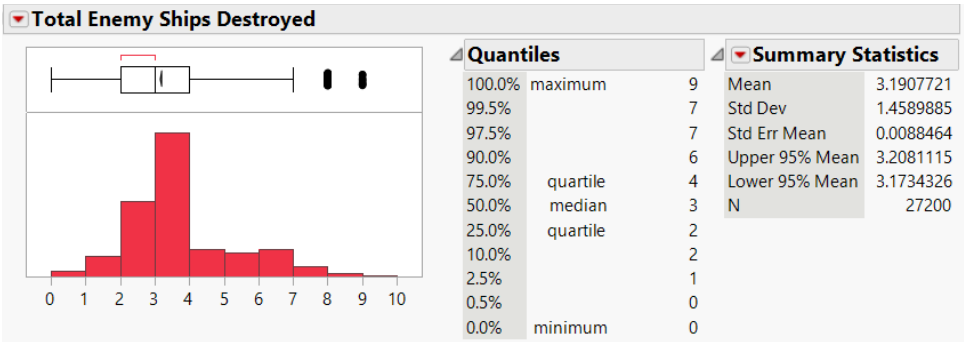
Second, in the "LMACC near" tactical template, the LRUSV is the vessel which is positioned the deepest in the MLR's battlespace. Since the LRUSV is the most numerous vessel in the simulation, positioning it as deep as possible in the battlespace provides denser reconnaissance coverage and allows the guard force to collect more information sooner on the enemy's composition and disposition. In short, more LRUSVs means each vessel is required to cover a smaller area. Additionally, even though the armed LMACCs are not as deep in the battlespace as in the "LMACC far" tactical template, having a portion of the guard force (i.e., the LRUSV company) positioned at least 100 nautical miles offshore appears to create the standoff, or "bubble," which is the impetus for the employment of the guard force in the first place. With earlier knowledge of the enemy's position and disposition, the LMACCs can fire more missiles sooner, resulting in fewer NSMs being fired and leading to fewer GBASM launchers being destroyed.

Finally, if we were to recommend shifting resources (read "allocate money") to focus on one factor from the survivability analysis, it would be LMACC quantity and that the LMACC flotilla consist of no less than six LMACCs.

C. ASSESSING FRIENDLY LETHALITY IN THE FULL EXPERIMENT

1. Lethality Summary Statistics

As is the case with the survivability assessment, when the MLR employs a guard force there is a modest increase in the number of enemy vessels destroyed. The mean number of enemy ships destroyed is 3.19, compared to a mean of 2.78 from the base case. Whereas in the base case experiment the enemy SAG met their disengagement criteria in all 49 runs, in the full experiment the enemy met their disengagement criteria in roughly 12,000 of the 27,200 battles. Full summary statistics for total enemy losses are displayed in Figure 28.



Quantiles

100.0%	maximum	9
99.5%		7
97.5%		7
90.0%		6
75.0%	quartile	4
50.0%	median	3
25.0%	quartile	2
10.0%		2
2.5%		1
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	3.1907721
Std Dev	1.4589885
Std Err Mean	0.0088464
Upper 95% Mean	3.2081115
Lower 95% Mean	3.1734326
N	27200

Figure 28. Summary statistics for enemy losses

The enemy’s losses by ship type closely mirror that of the base case as well. As indicated by Figure 29, the median number of Luyang IIIs lost is two, and the median number of Renhais lost is one. Again, the enemy is consistently losing unsustainable numbers of their most capable surface combatants. This can be partly attributed to the target precedence which was programmed into the behavior of the LMACC and GBASM agents. During construction of the scenario and agents, the research team programmed both the LMACC and GBASM agents to prioritize targeting the Renhai, then the Luyang III. This realistic target precedence prevented the LMACC and GBASM agents from firing on the less capable and less threatening Houbei missile boats.

Qty. Luyang Destroyed

Quantiles

100.0%	maximum	3
99.5%		3
97.5%		3
90.0%		3
75.0%	quartile	3
50.0%	median	2
25.0%	quartile	1
10.0%		1
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	1.9587132
Std Dev	0.955009
Std Err Mean	0.0057906
Upper 95% Mean	1.9700631
Lower 95% Mean	1.9473634
N	27200

Qty. Renhai Destroyed

Quantiles

100.0%	maximum	1
99.5%		1
97.5%		1
90.0%		1
75.0%	quartile	1
50.0%	median	1
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.7127206
Std Dev	0.4525014
Std Err Mean	0.0027437
Upper 95% Mean	0.7180984
Lower 95% Mean	0.7073428
N	27200

Qty. Houbei Destroyed

Quantiles

100.0%	maximum	5
99.5%		4
97.5%		3
90.0%		2
75.0%	quartile	1
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

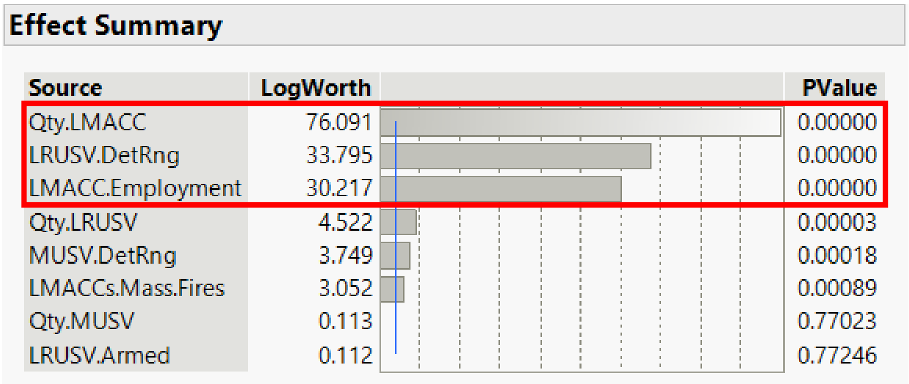
Summary Statistics

Mean	0.5193382
Std Dev	0.9717853
Std Err Mean	0.0058923
Upper 95% Mean	0.5308875
Lower 95% Mean	0.507789
N	27200

Figure 29. Summary statistics for enemy losses by ship type

2. Lethality Assessment, Conclusions, and Recommendations

To begin, the research team conducted a standard least squares regression using total enemy ships destroyed as the response variable and all eight experiment factors as predictors. As displayed in Figure 30, once again LMACC quantity is the most influential main effect in predicting enemy losses, outweighing the next factor in significance by a factor of two. The other top two main effects, LRSUV detection range and LMACC employment, are the same factors identified in the survivability analysis.

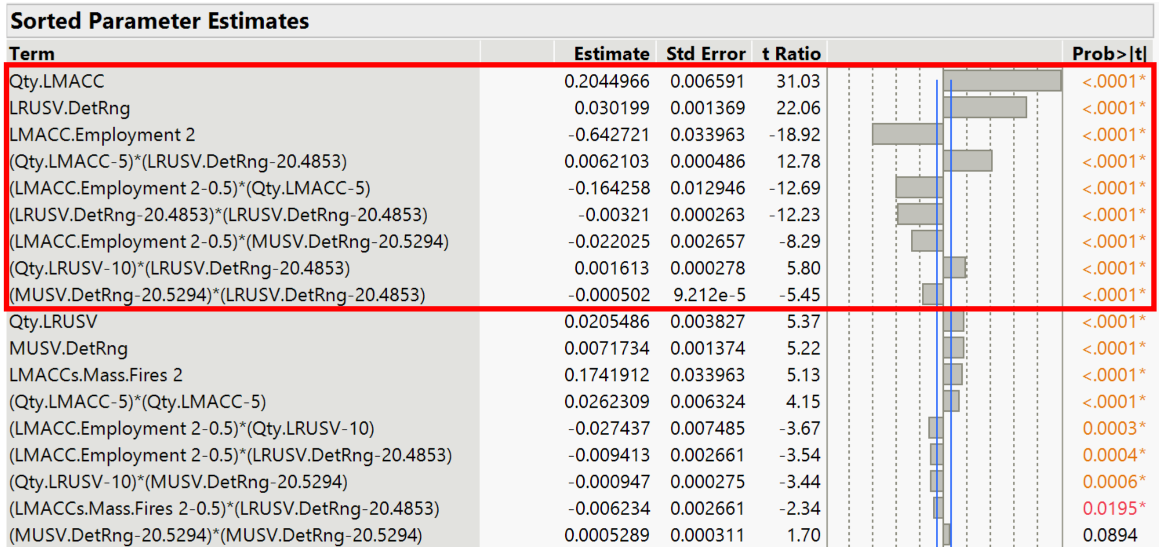


Effect Summary

Source	LogWorth	PValue
Qty.LMACC	76.091	0.00000
LRUSV.DetRng	33.795	0.00000
LMACC.Employment	30.217	0.00000
Qty.LRUSV	4.522	0.00003
MUSV.DetRng	3.749	0.00018
LMACCs.Mass.Fires	3.052	0.00089
Qty.MUSV	0.113	0.77023
LRUSV.Armed	0.112	0.77246

Figure 30. Lethality least squares regression

Next, the research team conducted a second order stepwise regression using the experiment's eight factors. The stepwise regression found six of these factors to be most relevant, and a linear regression was carried out using main effects, two-way interactions, and quadratic effects. In predicting the number of red ships destroyed, the resulting model weighs heavily the three main effects identified in the least squares regression as well as any interaction involving the top three factors. Figure 31 shows the sorted parameter estimates with the top nine factors identified in red; the R^2 for this regression is 0.84. The top nine factors are identified because the tenth effect is the first one that does not include the top three effects.



Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Qty.LMACC	0.2044966	0.006591	31.03	<.0001*
LRUSV.DetRng	0.030199	0.001369	22.06	<.0001*
LMACC.Employment 2	-0.642721	0.033963	-18.92	<.0001*
(Qty.LMACC-5)*(LRUSV.DetRng-20.4853)	0.0062103	0.000486	12.78	<.0001*
(LMACC.Employment 2-0.5)*(Qty.LMACC-5)	-0.164258	0.012946	-12.69	<.0001*
(LRUSV.DetRng-20.4853)*(LRUSV.DetRng-20.4853)	-0.00321	0.000263	-12.23	<.0001*
(LMACC.Employment 2-0.5)*(MUSV.DetRng-20.5294)	-0.022025	0.002657	-8.29	<.0001*
(Qty.LRUSV-10)*(LRUSV.DetRng-20.4853)	0.001613	0.000278	5.80	<.0001*
(MUSV.DetRng-20.5294)*(LRUSV.DetRng-20.4853)	-0.000502	9.212e-5	-5.45	<.0001*
Qty.LRUSV	0.0205486	0.003827	5.37	<.0001*
MUSV.DetRng	0.0071734	0.001374	5.22	<.0001*
LMACCs.Mass.Fires 2	0.1741912	0.033963	5.13	<.0001*
(Qty.LMACC-5)*(Qty.LMACC-5)	0.0262309	0.006324	4.15	<.0001*
(LMACC.Employment 2-0.5)*(Qty.LRUSV-10)	-0.027437	0.007485	-3.67	0.0003*
(LMACC.Employment 2-0.5)*(LRUSV.DetRng-20.4853)	-0.009413	0.002661	-3.54	0.0004*
(Qty.LRUSV-10)*(MUSV.DetRng-20.5294)	-0.000947	0.000275	-3.44	0.0006*
(LMACCs.Mass.Fires 2-0.5)*(LRUSV.DetRng-20.4853)	-0.006234	0.002661	-2.34	0.0195*
(MUSV.DetRng-20.5294)*(MUSV.DetRng-20.5294)	0.0005289	0.000311	1.70	0.0894

Figure 31. Most influential effects and their most significant interactions

To continue the analysis of friendly lethality, the research team constructed a partition tree to identify any additional important relationships between the factors. This partition tree took as its response variable the number of enemy ship's destroyed and used all eight of the experiment's factors as candidate predictors. As indicated by the previously conducted linear and stepwise regressions, the decisions tree's first split occurred on LMACC quantity. Just like in the survivability analysis, the partition tree indicated that six or more LMACCs (and subsequently the number of dispersed anti-ship missiles carried) is an inflection point for predicting enemy losses. When fewer than six LMACCs are employed, enemy losses averaged 2.64 ships per engagement; when six or more LMACCs are in the scenario, enemy losses averaged 3.74 ships per engagement. In Figure 32, the green boxes indicate the chain of friendly conditions which yield the best predicted outcomes for friendly lethality. Interestingly, these conditions are the same as in the survivability partition tree, with LRSUV detection range and LMACC employment switched in the order in which they occur.

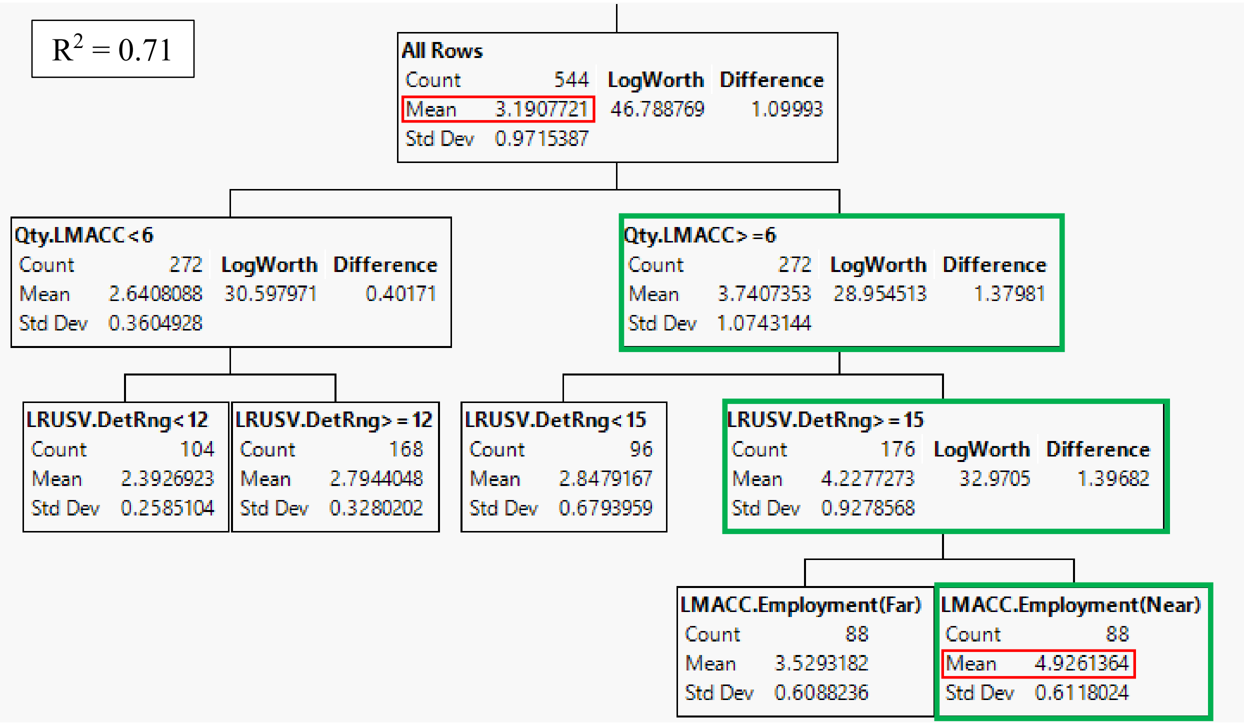


Figure 32. Partition tree for mean enemy ships destroyed

Of note is the predicted mean number of enemy ship's destroyed based on LMACC employment template. The partition tree's final split predicts a mean of 4.92 enemy ships destroyed, which is almost one and a half times the mean predicted by the alternative employment template. If a future platform or network of platforms can meet the conditions highlighted in green in Figure 32, the number of enemy ships destroyed increases from 3.19 to 4.92. This increase represents a significant increase in the cost the MLR can impose on an enemy force. Figure 33, a box plot representing the distribution of enemy losses, bears this out and it does appear that more enemy ships are lost when the "LMACC near" method is used.

Figure 33. Detailing enemy loss distributions by tactical template

Based on the preceding analysis of the experiment's outcomes, the research team offers the following analysis of friendly lethality.

There is a modest increase in the enemy ships destroyed from the base case. However, by increasing the number of LMACCs and positioning them closer to shore, the data suggests there will be an increase of one more enemy ship destroyed per engagement. One ship is not insignificant, especially if that ship is a Luyang III or Renhai. An Arleigh Burke-class guided missile destroyer, the U.S. equivalent of the Luyang III, costs approximately $1.84 billion USD. Losing one more Luyang III or Renhai per engagement is a very steep cost for our adversary to pay.

Second, the massing of fires by the LMACC flotilla was not as significant of a factor in lethality as anticipated. Intuition guided the research team to think that concentrating fires on a single enemy vessel and overwhelming its defenses would be more effective than each LMACC engaging targets independently.

Third, arming the LRUSVs with loitering munitions did not contribute meaningfully to the number of enemy ships *destroyed*. Given the size of the warhead on the loitering munition used in the simulation, it is unrealistic to expect a major surface combatant to be sunk by loitering munitions. However, the combat systems, sensors, and electronics located outside the skin of the ship are still vulnerable to loitering munitions. Disabling or destroying these systems can lead to a "mission kill" and force an enemy ship to retire. Additionally, the defended ship must expend ordnance or countermeasures against a swarm of loitering munitions, thus leaving the enemy ship less capable of defending against an anti-ship missile attack.

Finally, based on the lethality analysis, the research team once again recommends investing resources in the LMACC or a similar missile-carrying vessel. When armed appropriately, and employed in the appropriate quantities, the LMACC poses a credible threat to the enemy's major surface combatants. Additionally, a guard force using the LMACC, or an equivalently capable vessel, should include no less than six LMACCs. The author's analysis also suggests that the LMACC's anti-ship capabilities are enhanced when it partners with a scout equipped with long-range passive or active sensors, such as the LRUSV, to detect enemy ships and provide target location to the LMACC before the enemy ship senses the LMACC.

VI. CONCLUSION

> Stand-in forces are designed to generate technically disruptive, tactical stand-in engagements that confront the enemy with an array of low signature, affordable, and risk-worthy platforms and payloads.
>
> —Gen. David Berger, 38th CMC

This chapter provides a consolidated accounting of the findings and recommendations detailed in the previous chapter regarding survivability and lethality. Additionally, it contains conceptual findings and recommendations which relate to the USMC's Force Design 2030 initiatives and lines of effort. Finally, this chapter provides areas of further study that build upon the conclusions of this research as well as those of Captain Fitzmaurice and Majors Faucett and Howser.

A. SUMMARY OF FINDINGS AND CONCLUSIONS

1. Improving Survivability

The single most influential factor for predicting friendly survivability is the quantity of LMACCs in the guard force. Accordingly, the author recommends that the MLR guard force contain no fewer than six LMACCs or similar missile firing small combatant. More LMACCs in the guard force means more LRASM available, and the results of the simulations show that the number of LRASM fired is negatively correlated to the number of GBASM launchers destroyed, the number of NSM fired (fewer NSM fired means less exposure for the GBASM), and the number of Stinger missiles fired. In short, the more LRASM that are launched, the fewer GBASM launchers destroyed, and fewer shore-based defensive missiles fired.

Second, pairing the LMACC with a smaller scout is recommended. The partition tree predictions suggest that the LMACC is more survivable and lethal closer to shore, meaning there needs to be a platform deeper in the battlespace performing target acquisition for the LMACC. Also, since the LRUSV is less capable in terms of lethality compared to the LMACC, it is therefore more expendable. The LRUSV, serving as the eyes and ears of the guard force deep in the battlespace, can force the enemy into revealing his location and intentions earlier, affording the guard force commander the opportunity to attack from a direction or along an axis the enemy does not expect.

2. Improving Lethality

This study's analysis of friendly lethality reinforces the notion that the number of LMACCs is the most important factor in the experiment. The partition tree prediction creates a very decisive split at six LMACCs when predicting the number of enemy ships destroyed. Intuitively, employing more LMACCs puts more missiles in play and increases the chances of a missile getting through the enemy's defenses. Additionally, the same principles identified in the preceding section regarding the relationship between the LMACC and LRUSV endure in the lethality analysis. For the LMACC to be most lethal (and the most survivable itself), there must be some habitual relationship between the LMACC and a smaller, more expendable surface craft which can conduct reconnaissance and target location missions for the LMACC. Whether this is the MLR-owned LRUSV or another autonomous or semi-autonomous surface vessel owned by the USN is open for discussion. However, the lethality analysis strongly indicates the importance of no fewer than six LMACCs in the MLR guard force.

3. Final Thoughts

In the author's opinion, it is very significant that LMACC quantity and LRUSV detection range both contribute heavily to the models predicting friendly survivability and lethality. In the context of platform development and procurement, this means rather than pursuing myriad "fixes" to improve survivability and lethality, focusing resources on the maturation of just *two* factors will have considerable impact on the performance of the MLR's guard force.

The author would be remiss if the issues of force exchange ratios were not addressed. Frankly, the raw numbers of the exchange ratios are not favorable for friendly forces. The MLR consistently lost more units than the PLAN SAG. However, we must consider the cost ratio of losses based on the combat simulation. For instance, the PLAN SAG lost on average 1.96 Luyang III destroyers per engagement. If we assume that the cost of a Luyang III is comparable to that of a USN Arleigh Burke-class destroyer ($1.84

billion), then losing even a single Luyang III is a huge blow to the enemy in terms of capability and investment lost, not to mention the impact that such a loss would have on the enemy's ego and morale. By comparison, Professor Gallup estimates that a one LMACC will have a production cost of $96.6 million (Gallup 2021). As the CMC stated in his planning guidance, "Stand-in forces take advantage of the strategic offensive and tactical defensive to create disproportionate result at affordable cost" (Berger 2019, p. 11). In the opinion of the author, with the employment of a guard force similar to the one in this study, the MLR can successfully create disproportionate results.

B. RECOMMENDATIONS FOR FUTURE STUDY

1. Unclassified Future Studies

The possible future research concerning the lethality and survivability of the MLR is extensive. TM EABO contains draft Marine Corps tasks (MCT) for the MLR and its subordinate components. Combat simulation using MAST, Map Aware Non-uniform Automata (MANA), or any other type of modeling software is a very appropriate medium for exploring how well the MLR executes its MCTs and Mission-Essential Tasks (MET).

More specifically, lethality and survivability can be enhanced through an analysis of the MLR's ability to share a common operational picture (COP) and command and control distributed forces. An information sharing network with the capability and capacity to link numerous manned and unmanned sensors and shooters across thousands of square miles of battlespace is an integral part of a successful defense in the littorals. Further complicating the issue is the integration of joint assets such as the LMACC, MUSV, and UAVs. Future work could explore the network architecture required to maintain a COP, or perhaps the network's resiliency to interdiction.

There remains room for extensive combat simulation to assess the ability of the MLR guard force to integrate manned or unmanned aerial reconnaissance assets to determine the enemy's composition and disposition more quickly and accurately. The author deliberately omitted UAV reconnaissance from this combat simulation for the purpose of focusing on the performance of the surface vessels. However, the MLR and the guard force must be able to leverage aerial reconnaissance, across all domains, to remain well-informed as to the enemy's intentions.

Closely related to the use of UAVs for reconnaissance is the question of OPF employment by the guard force. A more detailed analysis is needed to determine the type of OPF, the quantity needed, requisite performance characteristics, and employment methods that exploit or create gaps in the capabilities of enemy ships.

2. Classified Future Work

To more thoroughly explore ways to improve the lethality of the MLR, the author recommends using classified performance data to model and simulate the performance of existing or future anti-ship missiles. The output of this work can be an assessment of the efficacy of existing systems and to establish more specific performance parameters for future systems.

Concerning survivability, there is ample opportunity to explore the impact of electronic warfare capabilities on friendly survivability. One scenario is to model the fielding of land-based, mobile jammers to augment the MADIS. Another possibility is adding a jamming capability to the vessels in the guard force to enhance their survivability.

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