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THESIS

**MARINE INFANTRY COMPANY LETHALITY:
AN ANALYSIS OF FORCE DESIGN 2030 PROPOSALS**

by

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June 2021

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DESIGN 2030 PROPOSALS**

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requirements for the degree of

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ABSTRACT

The composition of the Marine infantry company is changing to meet new threats. How will these evolutions affect the lethality, survivability, and employment of the future force? This research uses agent-based combat modeling techniques to provide insights for future live-force experimentation and wargaming. The author uses modeling software to simulate different infantry company configurations based upon Force Design 2030 proposals. The modeled scenario envisions a future Marine infantry company defending the flank of an expeditionary advanced base against a peer adversary conducting an amphibious assault. This research examines the size of the company engagement area and the implications of new and emerging technologies, such as loitering precision munitions, on the lethality and survivability of the infantry company. The author identifies the most effective tactics, techniques, and procedures discovered in the model. Based on 44,500 simulated battles, this research finds that in a conventional company-sized engagement, the force that finds and delivers sufficient loitering munitions to the other side first most often generates victory. This phenomenon can be understood in the context of a company's "throw weight," or the number of munitions it can use per salvo to engage enemy forces. The investigation also concludes that the future battlefield will be highly lethal, with all sides expected to experience significant attrition, even in victory.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Aviation Combat Element
ACV	Amphibious Combat Vehicle
CE	Command Element
C2	Command and Control
CPG	Commandant's Planning Guidance
DMO	Distributed Maritime Operations
DO	Distributed Operations
DOE	Design of Experiments
EA	Electronic Attack
EABO	Expeditionary Advanced Base Operations
EP	Electronic Protection
EW	Electronic Warfare
FRAGO	Fragmentary Order
FSCM	Fire Support Control Measure
GCE	Ground Combat Element
HAW	Heavy Anti-Armor Weapon
LAW	Light Anti-Armor Weapon
LCE	Logistics Combat Element
LOCE	Littoral Operations in Contested Environments
MAW	Medium Anti-Armor Weapon
MLR	Marine Littoral Regiment
NSFS	Naval Surface Fire Support
ROZ	Restricted Operations Zone
SACC	Supporting Arms Control Center
TTPs	Techniques, Tactics, and Procedures
UAS	Unmanned Aerial System
WEZ	Weapon Engagement Zone

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EXECUTIVE SUMMARY

The character of war is rapidly changing. The emergence of new technologies based upon advanced robotics, artificial intelligence, and energy storage enables precision, innovative platforms, such as unmanned aerial systems (UAS), optimized for attack, reconnaissance, and other functions. In addition to new technologies, geopolitical tensions in the western Pacific region are driving a realignment of the Department of Defense in accordance with new national strategic priorities. As a result of these trends, the Commandant of the Marine Corps published planning guidance in 2019 that initiated Force Design 2030. The force design review targets 2030 as the year the future force must be prepared to conduct combat operations. The envisioned future formation will operate within enemy weapon engagement zones as part of expeditionary advanced base operations.

The implications of the force design review at the small unit level are many. Marine infantry companies will see the most significant changes to force structure in decades if current proposals are accepted. These modifications promise to increase Marine lethality and survivability on future battlefields. Proposed changes fall into two categories: changes to tactics, techniques, and procedures (TTPs) and changes to equipment. Operational necessities will govern these two sets of changes as commanders seek to generate victory. At the Marine infantry company level, two critical questions emerge.

1. How might a future company commander best design their engagement area?
2. How much ordnance and of what type will a company require to engage an enemy force of a given size and type?

By answering these two questions at the company level, commanders can better prepare their forces for the future battlefield filled with loitering munitions, anti-ship missiles, and other factors yet to be invented.

To examine the two research questions, the author employed Map Aware Non-Uniform Automata Version V agent-based combat modeling and simulation software to

create a stochastic model of a Marine infantry company defense against a supported enemy amphibious mechanized company. The combat modeling process used an iterative, first-principles approach to first simulate the future Marine fireteam, and then scale the model to simulate an entire Marine infantry company with organic precision fires (OPF) loitering munitions. The combat model included two different OPF systems: OPF 1 class 1, an anti-personnel loitering munition, and OPF 1 class 2, an anti-armor loitering munition. The success of these two systems is key to the Commandant's vision of distributed operations at the small unit level—as they enable the massing of fires without the massing of Marines. The author used both current and proposed system specifications to build OPF model agents.

The red force in the model is based on the People's Liberation Army Navy-Marine Corps (PLAN-MC). The red force primary maneuver unit is an amphibious mechanized infantry company mounted in ZBD-05s. The red force company is modeled with both attack UAS support and naval surface fire support from higher-level naval assets. In the scenario, the red force seeks to seize key maritime terrain to set conditions for the destruction of a Marine Littoral Regiment (MLR). The blue force seeks to control that piece of key maritime terrain to prevent red force interference with MLR operations.

After model completion, the author created robust designs of experiments using nearly orthogonal Latin hypercubes, resolution V fractional factorial, and full factorial designs. The design of experiments enabled efficient model replications using high performance cluster computing. During experimentation and data collection, 44,500 different battles were simulated over several days, varying critical factors, such as probabilities of kill for OPF loitering munitions and communication latencies within the Marine kill web. Overall, the research design explores nine crucial factors, including OPF swarm size and blue force engagement distances.

Key recommendations from the research include:

1. To successfully conduct distributed operations, a Marine infantry company must have sufficient numbers of loitering munitions, no less than

10 OPF 1 class 2 systems, if relying solely on organic combat power to generate victory against a company-sized mechanized force.

2. Victory is best generated by the force that first finds and employs sufficient loitering munitions on the other side. Therefore, the future Marine infantry company must operate under a permissive fire support control methodology that enables OPF employment within its area of operations. The author recommends a restricted operations zone where the future company commander owns airspace to a sufficient altitude and can self-clear all fires in his domain.
3. High attrition is probable on the future battlefield if both sides employ precision loitering munitions. In the simulated battles that resulted in the blue force winning, the Marine infantry company, in particular instantiations, still took over 30% casualties. Future commanders must prepare themselves for this possibility and not let the enemy gain advantage by exploiting the resultant human factors in combat.
4. HAW-MAW-LAW is superior to mass surprised fires at the company level. This research found that ZBD-05s moving at three to five knots through the surf are highly vulnerable to OPF. Marine company commanders should seek to induce friction in the enemy system by engaging with OPF loitering munitions as early in a battle as feasible.

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DISCLAIMER

The contents of this thesis are for academic uses only. All scenarios, force structures, and employment methods are derived from unclassified materials. All modeling conducted during research was internally verified and validated without third-party review. The views expressed in this thesis are those of the author alone, and do not represent those of the Department of Defense, United States Marine Corps, or other government entities.

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I. INTRODUCTION

Force Design is my number one priority.

—38th Commandant

A. THE COMMANDANT’S MAIN EFFORT

The 38th Commandant’s Planning Guidance (CPG) calls for the realignment of the Marine Corps to its naval roots (Berger 2019). The refocusing of operational efforts to the Pacific Theater and designation of the 3rd Marine Expeditionary Force (MEF) as the main effort signals the opportunity for innovation. This innovation requires robust experimentation and wargaming to ensure timely, effective, and risk-worthy changes to the force.

B. THE PROBLEM

Many authors have written about the future operational environment in the *Marine Corps Gazette* and other publications over the past two years. In a 2019 article, Major General Mullen stated, “As the operating environment we face continues to change at what often seems like breakneck pace, the challenges will become increasingly complex. Many of these challenges are what is referred to as ‘wicked problems’ in that they do not have a solution” (Mullen 2019, p. 2). Furthermore, a renewed focus on great power competition against peer and near-peer competitors and realignment from the small wars of the early 21st century is taking place (Cuomo et al. 2019). The future battlefield will likely be characterized by great dispersion between units, precision loitering munitions, and numerous unmanned vehicles in the air, on land, and in the sea. These new and emerging technologies are forecasted to change the tempo and lethality of war.

The Commandant envisions a modern battlefield where the Marine Corps and Navy are capable of multiple concepts of employment under an umbrella operational paradigm (Berger 2019). The three main concepts of employment are distributed maritime operations (DMO), littoral operations in a contested environment (LOCE), and expeditionary

advanced basing operations (EABO). All three operations nest within the greater naval forces distributed operations (DO) concept, as illustrated in Figure 1.

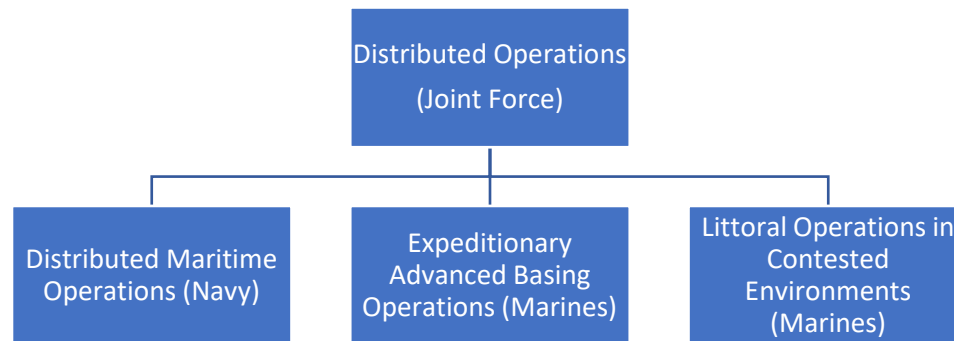


Figure 1. Distributed Operational Concepts

The importance of these concepts is captured in the Chief of Naval Operations’ first fragmentary order (FRAGO) of 2019. In his end state of the FRAGO, Admiral Gilday stated, “In order to maintain the maritime competitive advantage envisioned in our fleet design, we will ensure the wholeness of combat capable and lethal forces maximizing the benefits of Distributed Maritime Operations, Expeditionary Advanced Base Operations, and Littoral Operations in a Contested Environment” (Gilday 2019, p. 6).

No one definition exists for distributed operations. Rather, it is a collection of different concepts across the joint force with similar or complementary characteristics. These characteristics align with the overarching theme of trading efficiency for survivability and increasing the distribution of forces across the battlespace to counter anti-area access denial (A2AD) capabilities of near-peer or peer competitors (Priebe et al. 2019). The concept of DMO integrates naval composite warfare concepts and leverages Marine Corps EABO to support the fleet’s operational maneuver from the sea (Kerg, Dmochowski, and Hanacek 2019).

According to the *Expeditionary Advanced Base Operations (EABO) Handbook*,

EABO is a future naval operational concept that meets the resiliency and forward presence requirements of the next paradigm of U.S. Joint expeditionary operations. The concept is adversary-based, cost-informed,

and advantage-focused. The EABO concept is designed to defeat adversary attempts to execute counter intervention and fait accompli strategies that might otherwise inhibit a credible U.S. response to aggression against treaty allies and economic partners. (Corbett 2018, p. 5)

The handbook notes that “EABO is incorporated within LOCE, and is aligned with, and supports DMO and the Fleet Design initiative” (Corbett 2018, p. 22). The fusion of DMO with EABO conceptionally support each other to enable LOCE within the ever-expanding weapon engagement zone (WEZ) of potential adversaries. In aggregate, these concepts seek to mass fires without massing forces, thereby enabling lethality without exposing friendly forces to undue risk from enemy fires (Kerg, Dmochowski, and Hanacek 2019). In the photo below, multi-launch rocket systems displace from an airfield as part of an expeditionary exercise (Gosun 2021).



Photo courtesy of Lance Corporal Ujian Gosun

Figure 2. Exercise Castaway 21.1

Since before 2013, policy researchers envisioned a future where the Marine Corps employs land-based anti-ship missiles to complement naval operational maneuver from the sea (Kelly et al. 2013). The development of intermediate range anti-ship missiles in many national arsenals provides an opportunity to gain offensive striking power from an operationally defensive position. To understand missile warfare, an understanding of Hughes’ salvo equations is vital (Hughes and Girrier 2018). Quantitative analysis provides

insights into important factors such as quantity and quality tradeoffs. Hughes illustrates Admiral Nelson's adage that "a ship is a fool to fight a fort" (Hughes and Girrier 2018). This concept aligns with the Marine Corps effort to create mobile defensive positions with EABO and the enhanced striking power of ASMs to deter and defeat enemy aggression. Hughes and Girrier (2018) posit that to defeat a fort a naval force must either attack a lightly defended position or completely isolate the position being assaulted to prevent mutual aid from adjacent forces.

In a future conflict, enemy forces may seek to locate and destroy EABs with their strike capabilities. If the enemy cannot accomplish this due to the survivability of friendly EABs, an enemy force may conduct an amphibious assault with a counter lodgment force to isolate and reclaim key maritime terrain. EABs then must be able to defend themselves from these counter-lodgment forces. Suppose an EAB defends a critical and strategic piece of key maritime terrain, such as the Straits of Malacca. In that case, the enemy may deem its destruction vital to a greater naval campaign and devote large amounts of combat power to the EABs destruction.

The implications of these developing operational concepts for the individual Marine infantryman are enormous. In the past two decades, the Marine Corps has focused on counter-insurgency and small wars in Afghanistan and Iraq, and the continued deployment of Marine Expeditionary Units (MEUs). MEUs are "a forward-deployed, flexible, sea-based force that provides the President and the geographic combatant commander (GCC) with credible deterrence and decision time across the range of military operations" (DOD 2018, p. XI). While the Marine Corps will continue to deploy MEUs to support geographic combatant commanders, the structure and requirements of MEUs will change to meet the new operational paradigm. In addition to the MEU, the Marine Corps will composite a new formation called the Marine Littoral Regiment (MLR). The MLR is an organization optimized to persist within a WEZ. The proposed MLR will combine anti-surface, anti-air, expeditionary logistics, and highly mobile infantry capabilities to deter enemy aggression. MLRs provide a credible threat to enemy forces in closed littoral environments should future enemies seek to engage them (Berger 2019). From an infantry standpoint, this is a significant paradigm shift from closing with an objective in a

mechanized assault to providing highly flexible fixed and mobile security for assets controlled by the Joint Force Maritime Component Commander (JFMCC). The future center of gravity for the MLR is the anti-ship missile and its mission “naval strike.” Its mission is not the traditional combined arms assault of a Marine Air-Ground Task Force (MAGTF) (Hegmann 2020). In this new paradigm with great uncertainty, how might the future Marine infantry company operate to best add value to the Joint Force?

While these concepts establish a framework for future operations, the specific techniques, tactics, and procedures (TTPs) enabled by new and emerging technologies remain to be conceived, tested, and codified in a product consumable by future infantry company commanders. Many questions arise in examining the problem sets of the future operating environment. With such a rapidly changing character of war, it is difficult to predict what emergent properties will grow from new and emerging technologies and force structure.

Some broad age-old questions guide this research. The first question a commander may ask themselves in the defense is, “where will I kill the enemy?” The answer to this question defines where and how a company constructs an engagement area. The size and concept of operations for a given engagement area depend on the size of the defending unit, the type and amount of ordnance that unit has, and other supporting arms available to it. Unmanned systems and artificial intelligence (AI) are changing the character of engagement areas. New loitering munitions extend the reach of smaller and smaller echelons of warriors as miniaturization, and inexpensive manufacturing techniques continue to place more lethality in smaller packages. A commander in the future will be able to gain more standoff from their engagement area and greater organic precision in their unit, as they will be able to target faster and more accurately at greater distances using new platforms (Brose 2020).

The second question a commander may ask themselves is “how much ordnance and of what type do I need to win?” The answers to this question are varied and situationally dependent; however, identifying certain general trends, applicable across a wide variety of scenarios, is possible through robust analysis. Future commanders will have a mixture of reconnaissance UAS, attack UAS, anti-tank guided missiles (ATGMs), and more. In

expeditionary environments, the amount of material a unit can transport is limited. Decisions must be made by the commander on how many of these systems and pieces of ordnance to bring. Having too many light anti-personnel systems in a battle involving large numbers of light armored amphibious vehicles could be catastrophic. Conversely, bringing too many ATGMs with limited range will reduce the commander's competitive advantage against an all-infantry force conducting jungle warfare.

Finally, a commander may ask "how will I survive the opening salvos of the enemy assault?" The enemy gets a vote. Near peer and peer competitors are developing and have demonstrated capability with UAS systems (Chase et al. 2015), and land, ship, and air launched cruise and ballistic missiles (Heginbotham et al. 2015). To defend against these threats, and survive until the ground battle begins, a commander must consider taking a combination of steps. Historical air base attack data analyzed by RAND (Vick 2015) indicates the important factors for success are:

1. Camouflage, concealment, and deception
2. Hardening
3. On-base dispersal
4. Postattack recovery

What do these factors look like on the future battlefield, and how do commanders achieve them? Shown below, in Figure 3, is a Marine javelin team conducting a missile battle drill. Such battle drills will still be required; however, javelins alone may not be sufficient to counter future threats (Mesimer 2021). Furthermore, the current battle drill may not consider factors that will be present on the future battlefield.



Photo courtesy of Corporal Savannah Mesimer

Figure 3. Exercise Fuji Viper 21.2

These questions and concepts illustrate the massive nature of the “wicked problem” that faces today’s military planners and strategists. Marine infantry companies will be a small part of the solution. First principles thinking necessitates problem solving by starting small and improving ever-increasing size systems by iteratively focusing on making each element more effective. This technique is vital for breaking down this problem, and finding smaller solutions to small problems, which in aggregate will yield operational victory.

C. THE PROPOSED SOLUTION

To better inform planners, future testing and evaluation, and decision makers, simulation modeling with data farming techniques is employed to provide cost effective insights into the most important characteristics of the force and possible future techniques, tactics, and procedures (TTPs). Identifying these characteristics, also known as factors, will allow targeted investment in time, capital, and manpower to achieve more lethal outcomes by survivable future infantry companies.

D. SCOPE

This thesis focuses on company and company-supported operations against a near-peer or peer adversaries. It examines two questions:

- How might a future company commander best design their engagement area?
- How much ordnance and of what type will a company require to engage an enemy force of a given size and type?

The figure below highlights the complex system of systems that EABO requires. The red box outlines the infantry component of the problem set, the small piece that this thesis work examines.

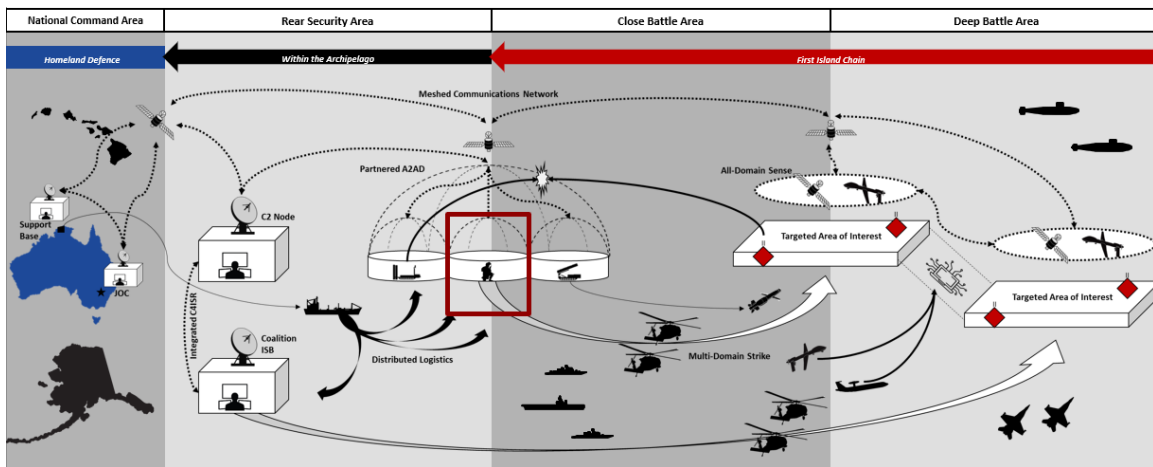


Figure 4. The Future Operational Framework

The scenarios examined align with the current force design proposals for the future infantry company. The study is based on micro-tactical scenarios and its results are meaningful to future company commanders and operations officers conducting company and battalion level operations. This thesis sets conditions for future work on the same topic as force design assumptions and planning is refined, and new and emerging technological capabilities are better understood.

E. METHODOLOGY

The following process was conducted to examine the future infantry company in the context of the problem statement:

1. Define measures of effectiveness (MOEs) for EABO operations.
2. Develop and model scenarios in Map Aware Non-Uniform Automata Version V (MANA-V) (McIntosh et al. 2007) to study the future operational environment.
3. Apply a robust design of experiments (DOE) and data farming techniques developed by the Naval Postgraduate School SEED Center for Data Farming (<https://harvest.nps.edu>) to examine a wide variety of factors at different levels.
4. Run the simulations and collect the output data.
5. Compute the MOEs from the output data.
6. Employ statistical modeling techniques to build metamodels that quantify the influence of different factors on the outcome of the scenario.
7. Analyze the metamodels to gain insights into how to design future forces and suggest TTPs.
8. Provide recommendations to stakeholders in the Marine Corps to inform future live force experimentation and wargaming analysis.

F. THESIS ORGANIZATION

Chapter II discusses the proposed changes to infantry concepts of employment and provides context to experimental design. It reviews what the changes are, how the changes apply to doctrine, and how these concepts are examined in MANA-V. Chapter III discusses model development. The scenario and corresponding factors and levels are explained along with key model assumptions. The limitations of the software are also discussed with proposed methods of overcoming important shortfalls. Chapter IV discusses the design of experiments, including factor selection, use of a nearly orthogonal and balanced design to explore the factor space, and the data farming process. Chapter V provides an analysis of the output data and experimental results. Finally, Chapter VI gives recommendations based upon the experimental results and suggests further areas for research by the Marine Corps and other entities.

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II. INFANTRY COMPANY OPERATIONS, FORCE DESIGN 2030 AND THE MODELING ENVIRONMENT

Stand-in forces take advantage of the relative strength of the contemporary defense and rapidly-emerging new technologies to create an integrated maritime defense that is optimized to operate in close and confined seas in defiance of adversary long-range precision “stand-off” capabilities.

—38th Commandant

This chapter provides background on infantry company operations and proposed Force Design 2030 changes. It seeks to inform the reader unfamiliar with these ideas to provide context for the model.

A. KEY COMPANY EMPLOYMENT CONCEPTS

Within a company defense, there are two key concepts that govern the employment of fires to destroy an enemy force. These concepts are “massed surprised fires” and “HAW-MAW-LAW.” (Headquarters, United States Marine Corps 2018b)

Massed surprised fires is the concept that a unit will remain covered and concealed until the decisive moment to engage the enemy. At the commander’s direction, or when a certain condition is met, the force simultaneously, or close to simultaneously, engages the enemy force to create shock and surprise. By engaging with all combat power at the same time, a commander seeks to mask his position until the decisive moment and not draw enemy fire. This concept requires an ambush mentality and traditionally does not take full advantage of the standoff capabilities of friendly weapon systems. It is often used whenever the enemy has an advantage in standoff weapon systems or armor. While difficult to achieve in higher echelon formations, the advent of loitering munitions being launched from multiple positions could change what massed surprised fires looks like. The surprise element in massed surprised fires can generate a disruption to the enemy system and if successful may lead to the destruction of the enemy force before it can competently react.

HAW-MAW-LAW stands for “heavy anti-armor weapons, medium anti-armor weapons, light anti-armor weapons.” This concept leverages the max effective range of friendly weapon systems. Heavy anti-armor weapons engage the enemy at the maximum

possible range. When the enemy reaches medium anti-armor weapon range, medium weapons are employed by friendly forces. Finally, when the enemy reaches light anti-armor weapons range, those weapons are employed. In aggregate, enemy forces are attrited over time as they move further into the friendly force weapon engagement zone.

B. FUTURE INFANTRY COMPANY OPERATIONS

The MLR is a formation optimized for future battles against a peer or near-peer competitor in the littoral areas of the world. It combines the long-range strike capability of land-based anti-ship missiles with the security of an infantry battalion and sustainment of an expeditionary logistics combat element (United States Marine Corps 2021). The MLR can employ HAW-MAW-LAW to influence the operational level of war. As part of a defense of the EAB, a Marine infantry company may employ HAW-MAW-LAW using organic precision fires or mass surprised fires, depending on the scenario (Headquarters, United States Marine Corps 2018b). While the nature of defensive missions of the Marine infantry remains relatively the same as in the past, the character of those defensive missions is changing due to new and emerging technologies.

The mission of Marine infantry is to locate, close with, and destroy the enemy by fire and maneuver or repel their assault by fire and close combat (Headquarters, United States Marine Corps 2018a). This mission contributes to sea control and sea denial by the MLR through the protection of “kill assets” such as anti-ship missile batteries. In a great power competition environment, the protection of such assets is extremely challenging, especially within the enemy WEZ. Enemy threats to the force include the following non-comprehensive list:

1. Strike capabilities (surface-to-surface, air-to-surface)
2. Anti-lodgment forces (conventional attack)
3. Special operations forces (SOF)
4. Insurgent forces (state backed or non-state backed)

In a general conflict, a hybrid strategy that combines these assets could be used to contest the MLR’s activities.

Future Marine Infantry Companies will be asked to conduct a wide variety of missions in support of the MLR in expeditionary environments. These missions may include:

1. Fixed site security
2. Mobile/convoy security
3. Seizure of key terrain
4. Defense of key terrain
5. Attack against an enemy force

In that future environment, it is unclear what sized enemy forces a Marine Company may be matched against. This research specifically examines what size counter lodgment force a Marine infantry company can defend against. By better understanding relative combat power, a commander may better employ such a future company in economy of force operations. Furthermore, these examinations will aid the commander in understanding if a company can achieve massed fires without physically massing platoons in a traditional linear defense.

C. FORCE DESIGN 2030

Lance Corporal James Duncan lay low in his fighting position. Incoming waves of enemy UAS circled overhead searching for targets in the dense jungle undergrowth. Beyond the sand dune 800 meters to LCpl Duncan's front, an enemy platoon massed in defilade. He quietly activated the attack UAS pre-laid in a small clearing 100 meters from his position. The small quadcopter lifted off through a break in the trees and quickly moved to the pre-designated waypoint. As the quadcopter crested the dune, the enemy appeared LCpl Duncan's tablet. Targets populated the screen as the quadcopter assessed its sight picture. After gaining positive identification of the threat, LCpl Duncan engaged. The attack UAS buzzed into a cluster of individuals with two radios and detonated, spalling fragmentation through the enemy ranks. LCpl Duncan slipped his tablet into his Ferriday case, and moved to his secondary position.

Future expeditionary environments will require the integration of large numbers of capabilities at the company level. Placing more capabilities in company organic, properly sized packages will allow a company commander to conduct timely operations on the battlefield. The author envisions one small kill chain in the opening vignette. In that scenario, one Marine and one UAS operate with little oversight. Now imagine that scaling to dozens of UAS and Marines working independently but needing to synchronize their actions simultaneously.

The intent of these changes to the Marine infantry company is to make smaller units more survivable and lethal. Specific proposed changes involve both personnel and equipment. Key proposed table of organization and equipment (TO&E) changes included in the *Tentative Manual for Expeditionary Advanced Base Operations* include (Headquarters, United States Marine Corps 2021):

1. Anti-armor teams -- each company will include multiple anti-armor teams with javelin missiles organic to the company headquarters.
2. Enhanced logistics capability -- each company will include a more robust logistics package with specialists for planning and execution of expeditionary operations.
3. Enhanced fires clearance and control -- each company fires support team will be augmented to be more robust and able to clear fires in the company battlespace.
4. Organic precision fires with loitering munitions -- each company, platoon, and squad will have the ability to conduct precision strikes with future loitering munitions that enable better targeting at further distances.
5. Anti-armor weapons at the squad level -- each squad will have a medium anti-armor weapon (MAAW). The variety of available rockets for the system will enable squads to engage point targets with high explosives at greater distances, such as light amphibious mechanized vehicles.

6. Future infantry Marines will have enhanced communications equipment that provides the rifleman to the company commander a better common operating picture (COP) to drive maneuver warfare.
7. Ultra-Light Tactical Vehicles (ULTVs) will be employed down to the squad level to increase mobility and carrying capacity of infantrymen.
8. Joint Light Tactical Vehicles (JLTVs) will be employed at the company level to support logistics, communications, and fires.



Photo courtesy of Corporal Jose Marquez

Figure 5. Jungle Reconnaissance

Pictured above is a Marine moving through dense jungle. If not for the different rifle and helmet, this photo could be from the Vietnam War or Guadalcanal (Marquez 2021). The character of war is changing rapidly with new and advancing technologies. These changes provide an opportunity to fuse the new and old into a new, more lethal iteration of maneuver warfare. Modeling and simulation can be used to assess the potential impacts of these new technologies that are not yet fielded.

D. MAP AWARE NON-UNIFORM AUTOMATA (MANA-V)

Map Aware Non-Uniform Automata version 5 (MANA-V) is a stochastic, time step, agent-based distillation modeling software. It was created by the Defence Technology Agency, in Auckland, New Zealand for employment in military operations research. MANA was specifically selected for employment in this thesis due to its flexibility in modeling complex kill chains through sensor shooter agents linked with different communications networks (McIntosh et al. 2007). Under the MANA paradigm, agents are combined into squads with different characteristics that mirror sensors and weapon systems—both current and proposed. The size, composition, and personalities of different squads can be changed to model real world behavior, and study different interactions in simulation which cannot be studied in live-fire experimentation. Limits to live-fire experimentation in this context are due to many of these technologies not existing yet in the prescribed form, and limitations to time and funding due to current operational tempos in the Fleet.

Throughout the modeling process, MANA enables the layering of command-and-control networks between squads and agents. This functionality enables the exploration of network latency and message corruption. Additionally, the echeloning of fires in the attack and defense can be controlled through these networks.

As with all modeling environments, MANA has limitations and assumptions must be made. The MANA environment is statistical in nature rather than being a physics-based model. MANA is not predictive, but rather allows researchers to identify model-based trends which are important to senior decision makers and the logical consequences that follow from a set of inputs.

III. MODEL DEVELOPMENT

To date our wargaming has focused on a limited set of scenarios; thus, we will need to expand our analysis across more scenarios to better inform our force design efforts.

—38th Commandant

This chapter examines the iterative model development process. It describes the constraints, limitations, and assumptions of the model and modeling environment and how those factors drove scenario development.

A. THE SCENARIO

To select a proper scenario location and enemy composition, the author first consulted the *Tentative Manual for Expeditionary Advanced Base Operations* (Headquarters, United States Marine Corps 2021). Key requirements include the following:

1. Littoral environment mirroring future potential EAB sites.
2. Large enough for a company-sized element, including a company-sized restricted operations zone and other fire support coordination measures.
3. Not a specific location identified for future operations or a location that could be construed as such.

This thesis intends to provide a baseline for inputs into live-fire experimentation and wargaming; therefore, the author selected Camp Pendleton as the map location for modeling purposes to meet the above criteria. In addition, the modeled area is easily and inexpensively accessible to the Marine Corps for live experimentation and is known to the author. A decision-maker could read this thesis and conduct a terrain walk with Marines to discuss the scenario on the simulated terrain. Professional development exercises, such as “tactical exercises without troops” or command post exercises, can be used to examine this thesis’ recommendations and outcomes further. A map of the scenario area is shown in Figure 6.



Figure 6. Camp Pendleton Model Scenario Map

The terrain map used to simulate Camp Pendleton, or “model playboard” is 150 nautical miles by 150 nautical miles. Depicted in Figure 7, it captures the corridor from San Diego to Los Angeles.

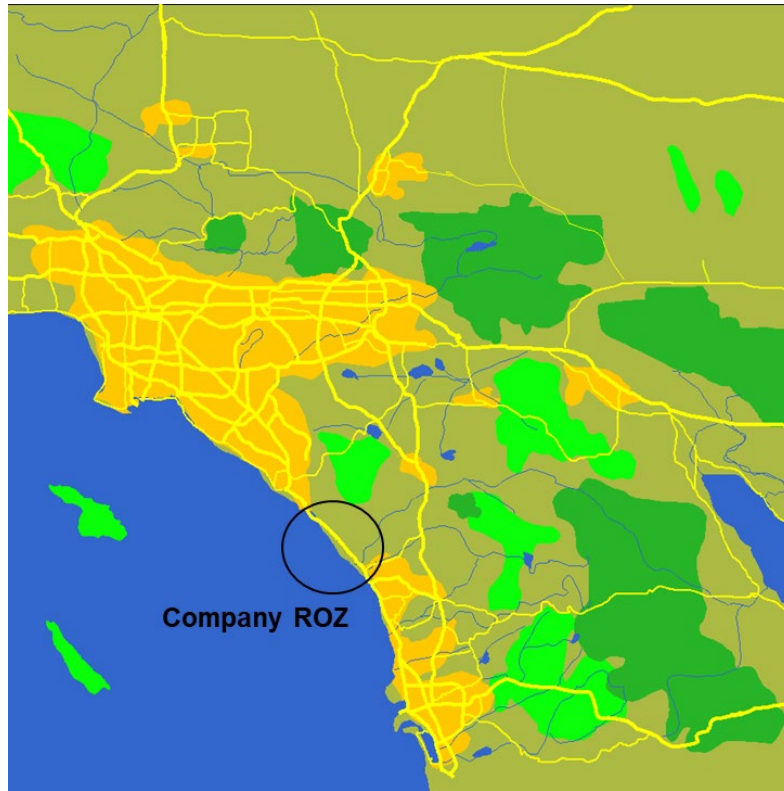


Figure 7. Model Terrain with Company ROZ Overlay

While the used engagement area in the simulation is the company restricted operations zone (ROZ) overlaid on the terrain map, the author chose a much larger model playbox to enable future research. Future iterations of the base model in this thesis could include anti-ship missiles and other parts of the MLR.

Each time step in the scenario models two seconds of time. The model runs for ten-thousand-time steps, or approximately 5.5 hours of simulated battle. The purpose of two second time steps is to achieve high fidelity on agent action without making the computation requirement for each scenario to be onerous. If time steps are too large, then differentiating hits and kills becomes less precise. If time steps are too small, the computational time and model run time on processors becomes too long.

The friendly unit modeled is a future infantry company envisioned in Force Design 2030 (Headquarters, United States Marine Corps 2021). The modeled formation is conducting a defense while dispersed in the littoral terrain against an anti-lodgment

amphibious enemy force. The enemy force mission is to seize the key maritime terrain occupied by the friendly expeditionary advanced base the Marine company is part of. The mission of the Marine infantry company is to control the key maritime terrain to prevent interference with MLR operations.

In such a scenario, the Marine infantry company engagement of the enemy force would be part of a greater concept of operations. It would be expected that Marine Littoral Regiment (MLR) assets such as anti-ship missiles would be employed against enemy assets to reduce the risk to the EAB if the enemy sought to dislodge it. Additionally, defensive counter air and surface-to-air missiles would be expected to provide anti-air defense. These two factors are not modeled and should be part of future modeling and simulation efforts.

For the purposes of this thesis, the author chose to focus solely on a company-sized force of Marines. This focus aligns with a first principles approach, where the author seeks to start modeling with smaller kill chains at the fireteam level, and slowly progress through squad and platoon sized modeling efforts to a final company sized model. Modeling small interactions first, such as a squad employing an attack UAS against enemy infantry, allowed the author to ensure better fidelity to real-world outcomes. By more accurately modeling real interactions on the battlefield at a smaller level, the author sought to find more accurate trends in the analysis when the multiple, complex kill chains within a future Marine infantry company were aggregated into a full company-sized model. The diagram below shows the ground up approach from build 1 to build 8 as smaller force and kill chains were layered upon each other to create the company model.

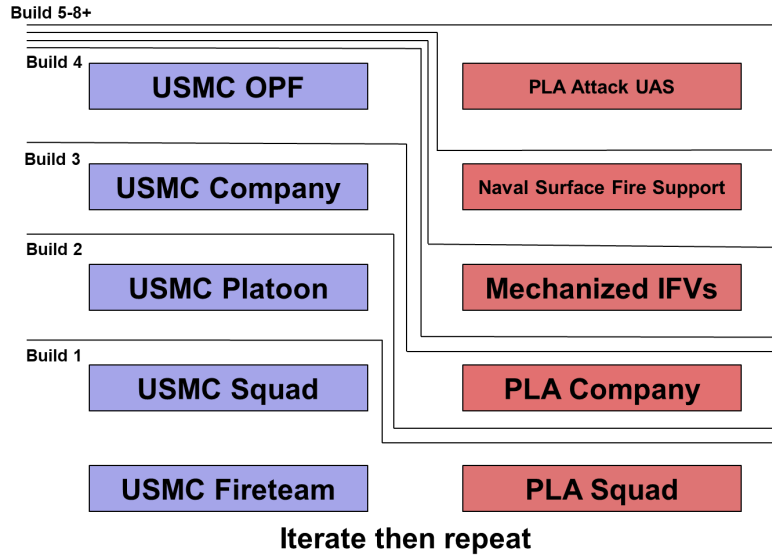


Figure 8. Model Design Process

The first build of the model focused on accurately simulating blue and red squads. The second build aggregated three blue squads into a platoon to ensure proper command and control and kill chain networks. Each build layered until the full model was constructed that included a full organic Marine infantry company engaged against a supported red mechanized infantry company.

B. BLUE FORCE AGENT DESIGN

Agents in the simulation range from fireteams to UAS. Red and Blue fireteams are each an aggregated agent that represent multiple combatants. Hit requirements to kill fire team agents correspond to the number of templated combatants in the fireteam. Each red and blue UAS on the battlefield is also an agent. UAS swarms are squads comprised of multiple UAS agents.

A Marine infantry squad, show in Figure 9, is comprised of three agents: two fireteam agents and a squad headquarters agent. Each fireteam agent represents six Marines. In addition to basic rifleman loadouts such as M27 rifles and fragmentation grenades, one fireteam is equipped with a medium anti-armor weapon (MAAW), and one fireteam with an M240B medium machine gun. The squad headquarters represents the squad leader, assistant squad leader, and UAS operator.

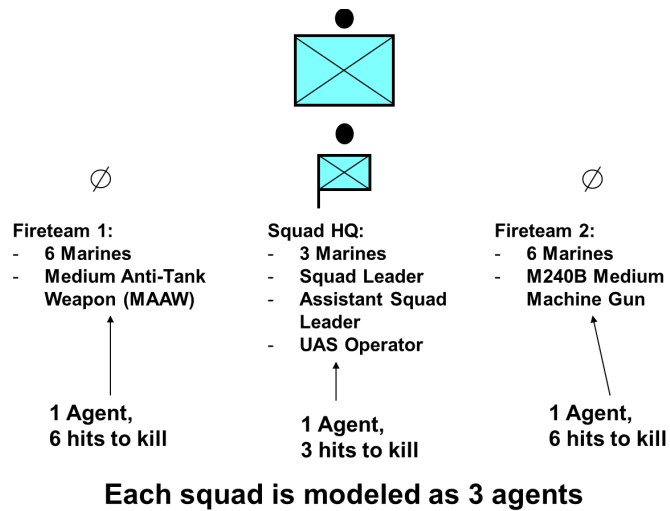


Figure 9. Squad Level Modeling

Each Marine platoon is comprised of three squads and a platoon headquarters agent. The platoon headquarters consists of the platoon commander, platoon sergeant, and radio operator. Each platoon possesses organic precision fires one class one UAS. For simulation purposes, these are templated as anti-personnel fragmentation warhead attack UAS. Figure 10 summarizes the platoon design.

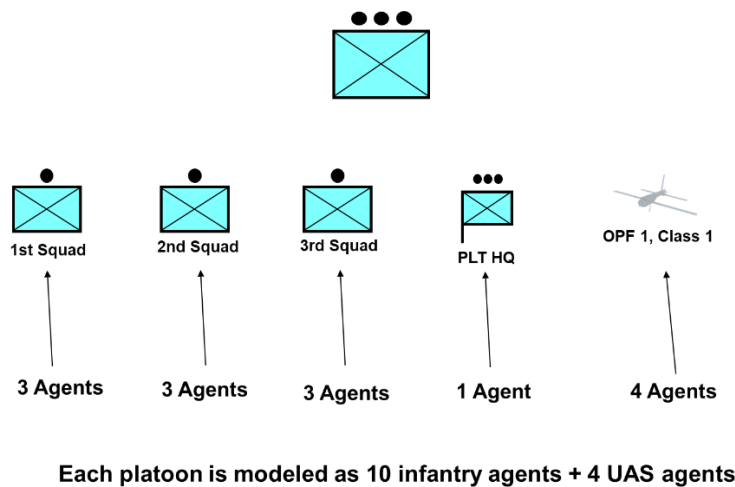
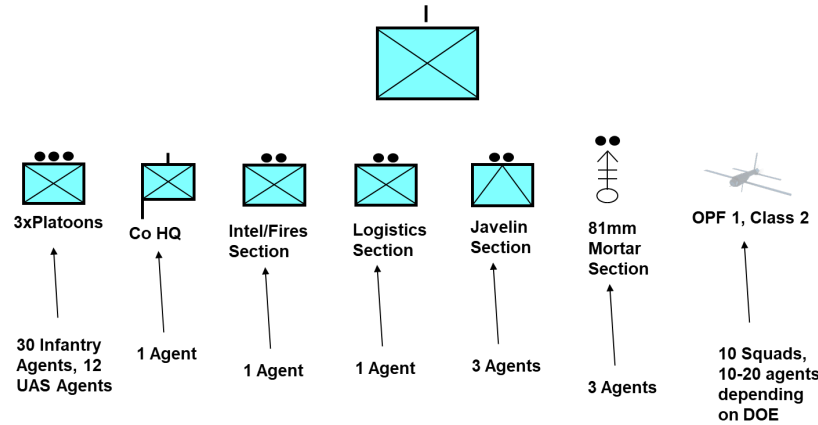


Figure 10. Platoon Level Modeling

The Marine infantry company includes three platoons, a company headquarters agent, company fires/intelligence agent, company logistics agent, 81mm mortar section, and three javelin teams. The company fires and intelligence cell possess organic precision fires one class two UAS. These UAS are templated as anti-armor capable shape charge warhead attack UAS. The company design is summarized in Figure 11.



Each company is modeled as 39 infantry agents + 22 to 32 UAS agents

Figure 11. Company Level Modeling

C. RED FORCE AGENT DESIGN

The red force infantry squad is comprised of two fireteam agents. Each agent takes five hits to kill to represent the five individuals in each fireteam. Every red fireteam has a medium machine gun, rocket propelled grenade launcher, and three rifles. The parent unit for each squad is an amphibious infantry fighting vehicle.

The red amphibious infantry fighting vehicles are modeled from ZBD-05s (Janes 2021). Each ZBD has a 30mm canon, coaxial machine gun, and two red arrow anti-tank guided missiles. They are capable of traversing water at 3–5 knots and moving 25 kilometers an hour across the beach.

Each red amphibious mechanized infantry company is comprised of 10 ZBD-05s and 10 infantry squads. Each squad is embarked in a vehicle to start the simulation and

disembarks when certain criteria are met. One ZBD-05 houses the company commander and one ZBD-05 houses the company executive officer. These ZBDs are modeled as having more robust communications suites to communicate with ships and other red assets to call for and coordinate supporting fires.

Red naval assets include an amphibious ship and a missile corvette. The missile corvette can provide naval surface fire support with land-attack missiles and is templated to have a magazine capacity of 10 missiles. Fires coordination for the missile corvette flows through the amphibious ship to simulate a fire support coordination center. On board the amphibious ship are UAS swarms capable of supporting the amphibious infantry company with reconnaissance and loitering munitions. Each swarm is a squad of four agents with anti-personnel fragmentary warheads.

Table 1. Red Force Design

Name	Class	Number of Squads	Agents per Squad/Hits to Kill	Weapons	Notes
PLAN-MC Squad	Crew Served Weapon	10	2/5	RPG; PKM; AK74	Basic Maneuver Unit
ZBD-05 Amphibious Infantry Fighting Vehicle	Armor	10	1/1	30mm Canon; Coaxial Machine Gun; Red Arrow ATGMs	1:1 Parent Unit ratio to squads
Type 075 Amphibious Assault Ship	Ship	1	1/1	Medium Red UAS; naval guns	C4ISR Node
Medium Red UAS	UAS	4	4/1	Medium Warhead	Adds fire support to PLAN-MC units
Missile Corvette	Ship	1	1/1	Land Attack Missiles	Adds fire support to PLAN-MC units

D. BLUE CONCEPT OF OPERATIONS AND SCHEME OF MANEUVER

The mission of the Marine company is to block enemy forces in order to prevent disruption of expeditionary base operations. The Marine company concept of operations is to mass fires from three different platoon-sized positions using attack UAS envisioned in the Organic Precision Fires (OPF) capability set. The platoons are camouflaged and will only engage with direct fire weapons if directly threatened by the enemy force as to not

give away their position. Pictured below is a rendering of a defense where Marine units use the micro terrain of the coastal hills to mask their positions with cover and concealment.



Figure 12. Blue Force Laydown

Included in the defense is a section of two 81mm mortars to provide indirect fire capability to the company commander. A key assumption of the blue defense is that the company is operating within its own restricted operations zone in which the company may use the entirety of its organic capabilities without clearance from the battalion fire support coordination center. It is assumed that the engagement criteria, rules of engagement, and fire support coordination measures are structured to maximize the company commander's flexibility and responsiveness in his sector. Key kill chain decision trees are shown below in Figures 13–16 to visualize the agent engagement criteria for different blue weapon systems.

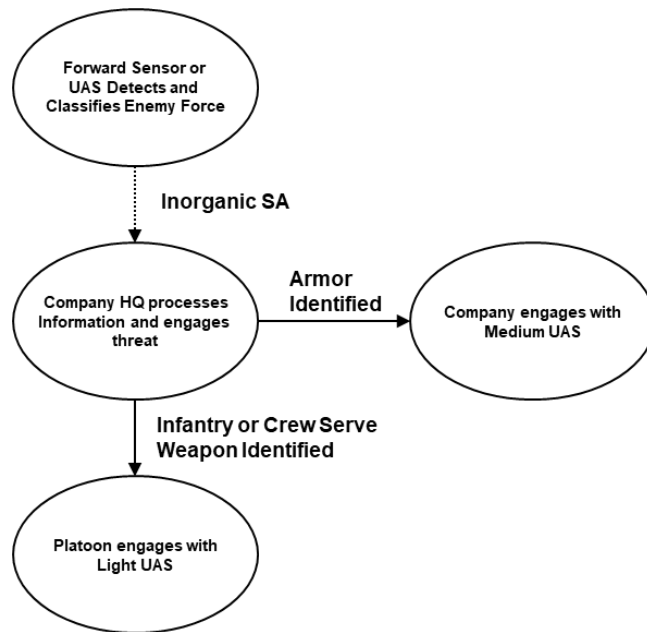


Figure 13. UAS Kill Chain from Forward Sensor

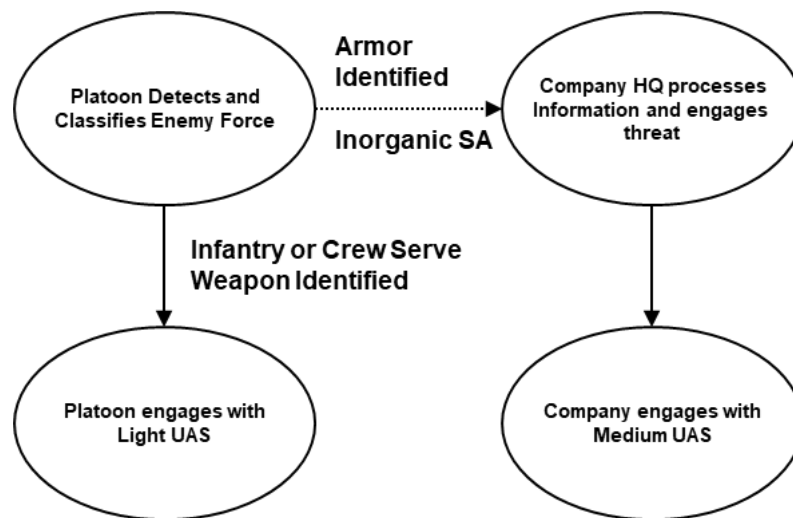


Figure 14. UAS Kill Chain from Platoon Detection

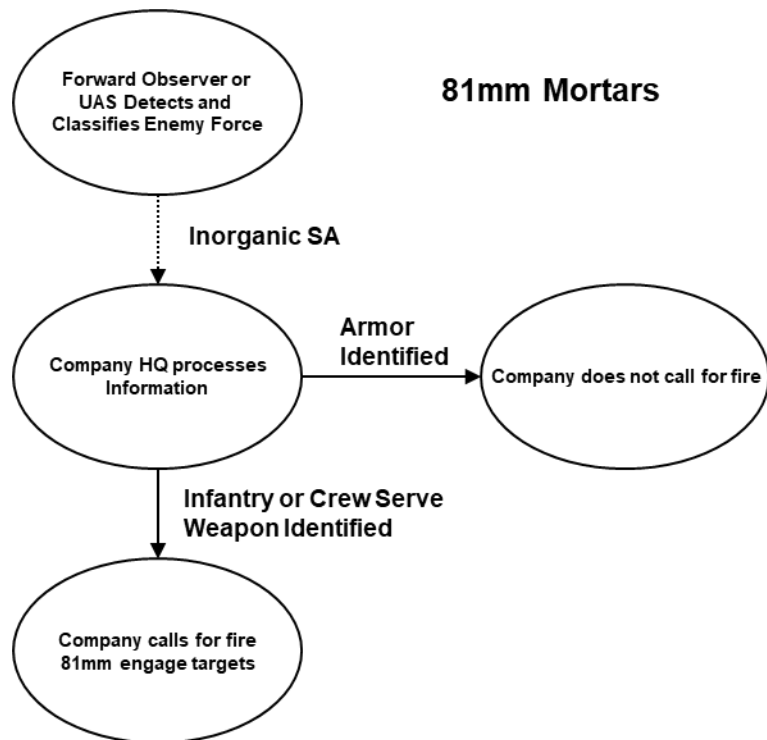


Figure 15. 81mm Kill Chain

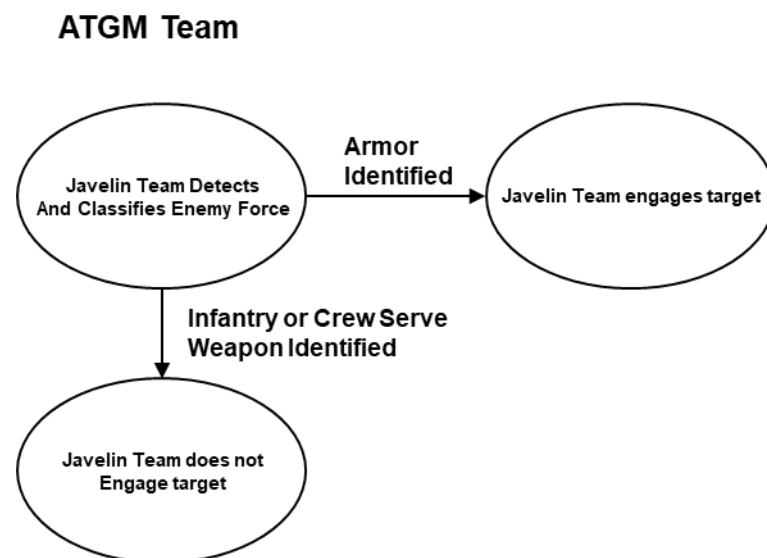


Figure 16. ATGM Kill Chain

The Marine company will employ its organic fires to attrite the enemy as it approaches the beach. It is assumed that the Marine company will not mass into a linear defense due to the risk from the enemy's reconnaissance and fires assets. It is also assumed that the Marine company will seek to minimize movement which could be detected by enemy reconnaissance assets. The Marines will operate from their cover and concealment and only expose themselves if necessary or at a decisive moment when they can gain a decisive advantage.

Victory conditions for the Marine Company is destruction of the first wave of the enemy landing force, the red amphibious mechanized company. The decisive destruction of the first wave of enemy forces could have a disruptive effect on the enemy scheme of maneuver by delaying their operations, buying more time for EAB displacement, or the arrival of joint combat power able to destroy the enemy fleet.

E. RED CONCEPT OF OPERATIONS AND SCHEME OF MANEUVER

The overall red force mission is to block the coast highway in order to prevent expeditionary base displacement. The enemy concept of operations is to employ attack and reconnaissance UAS and land-attack missiles to support the landing of an amphibious mechanized company on the coast. The mission of the enemy mechanized company is to establish a blocking position on the coastal highway to facilitate the maneuver of follow-on forces. It is assumed that the red force in the model would be operating as part of a larger naval task group. By limiting the model to a portion of the battle, better fidelity on battle outcomes is obtained. The amphibious approach of the red force is shown in Figure 17.

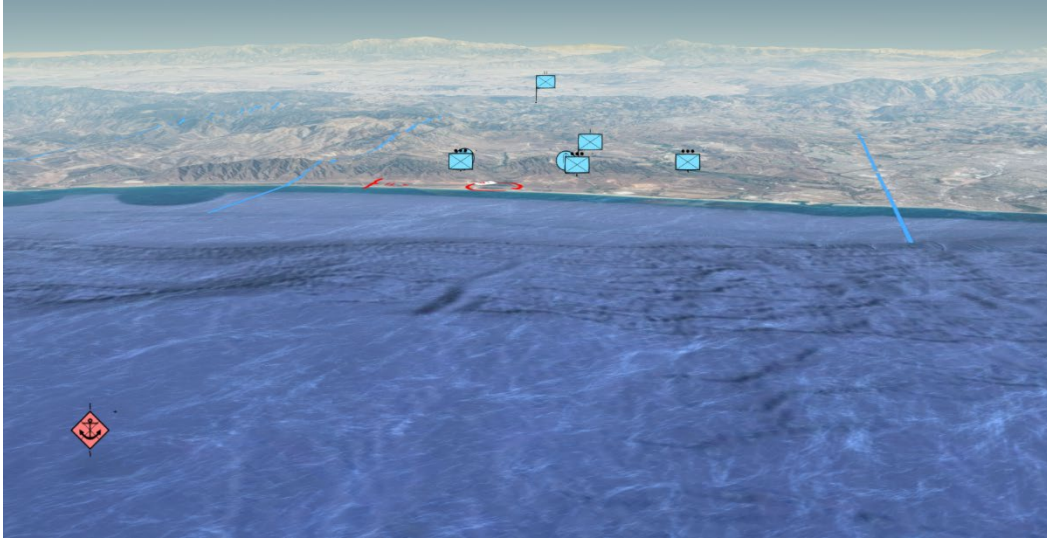


Figure 17. Red Force Amphibious Approaches

The red force victory condition is the successful occupation of a blocking position on the coastal highway. If any red forces remain on the objective, it is considered a red victory. Combined, the red and blue schemes of maneuver and geometries of fire can be visualized using Figure 18 below.

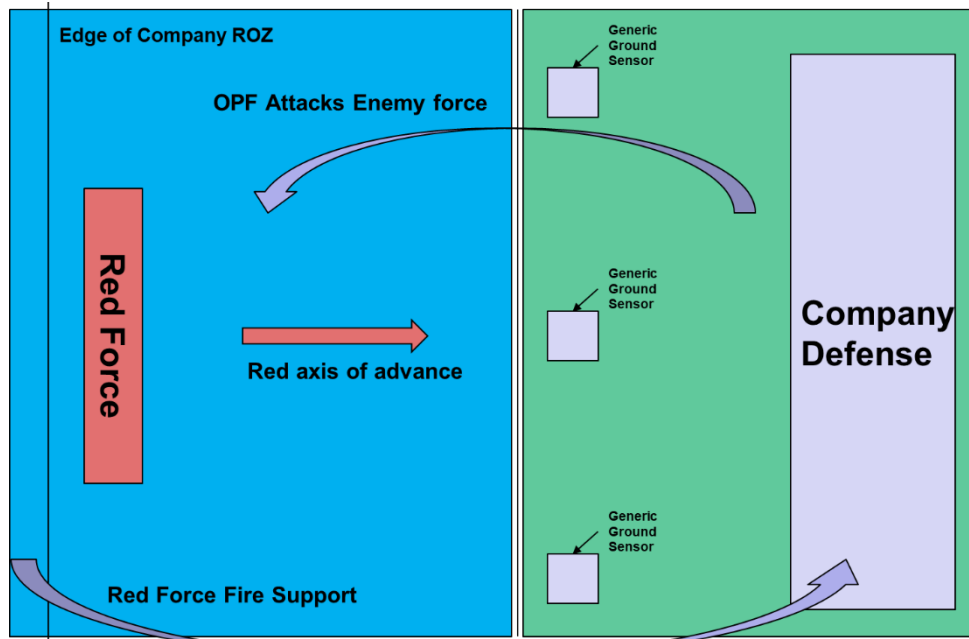


Figure 18. Geometries of Fire

For modeling purposes, generic ground sensors are placed at the water's edge. These sensors allow experimentation with how far from the beach the blue force can sense the red force. By simplifying this process with the three ground sensors, the modeling can examine reconnaissance and counter reconnaissance in an unclassified setting without modeling specific agents.

F. MEASURES OF EFFECTIVENESS (MOES)

The key Measures of Effectiveness (MOEs) examined in this thesis are:

1. Total red ZBDs destroyed during a simulated battle.
2. Total blue force casualties during a simulated battle.
3. Blue achieving victory at the end of a simulated battle.

These MOEs are designed to capture the survivability and lethality of the Marine infantry company. The first MOE, total red ZBDs destroyed, captures blue force lethality during the battle. The second MOE, total blue force casualties, captures the survivability of the blue force during the battle. The third MOE, blue achieving victory, captures whether the operational requirements of the blue force are met during the battle. This specifically is measured in whether the red force establishes a blocking position on the key terrain overlooking the coastal highway by the end of the battle. If there are no remaining red forces on that objective, then it is a blue force victory. The outcomes from the simulation in each of these MOEs can inform battalion and MLRs firing planning documents such as an Attack Guidance Matrices (AGM), a document that prioritizes classes of targets and guides weapon to target matches.

It is important to note that red infantry casualties were not used as a measure of effectiveness in the model. Red infantry casualty metrics were collected, however, through iterative modeling the author found that they were not very informative. During model development the survivability of the red force infantry was found to be very low, especially in the presence of blue force OPF 1 class 1 systems. If red force infantry survived, then there were always surviving red force ZBDs. If all red force ZBDs were destroyed, then all red force infantry would also always be destroyed. This phenomenon occurred because of

the lethality of the blue OPF 1 class 1 systems and mortars. The disaggregated blue forces destroyed remaining red infantry on the red force objective if any remained even if they did not have enough anti-armor assets to destroy the remaining ZBDs. Through the iterative process, the author found that measuring remaining ZBDs was a much better measure of blue force lethality during a simulated battle because the red force's ability to generate victory entirely depended on if ZBDs survived. This finding is more closely examined in Chapter V on model analysis.

G. MODEL ASSUMPTIONS

This section aggregates the assumptions of the model for quick reference.

Red Assumptions:

1. Calls for fire support by the red mechanized company will originate from the company commander or executive officer. If both are dead, then no calls for fire will originate from the red company. This assumption is based on PLA formations being hierarchical and naval surface fire support complex. The author assesses that NCOs in ZBDs without advanced communication suites will be unable to accurately call for and clear fires.
2. If available, the red force will send out an advanced UAS swarm in front of the mechanized company as a reconnaissance element. This forward element is composed of dual use UAS which can both loiter for reconnaissance purposes and attack after finding the correct target.
3. Calls for fire from the mechanized company, land attack missile strikes, or other strikes using reconnaissance/attack UAS will pass through the red amphibious ship, which will either launch a UAS swarm in response or coordinate land attack missiles through the missile corvette. This assumption is predicated on a supporting arms coordination center being required to deconflict airspace and enforce fire support coordination measures.

4. The red missile corvette will be limited to 10 land attack missiles. (Janes 2021)

Blue Assumptions:

1. The infantry company will not attack enemy shipping with their OPF system. It is assumed that battalion and higher levels would target enemy ships in this scenario. Additionally, the anti-ship effects of attack UAS are unknown to the author and beyond the scope of this study.
2. The company only operates on doctrinal networks, i.e., a fireteam will not call the company headquarters for fire support. In extremis, this is possible, but was not modeled as MANA-V has limitations in modifying C4ISR networks during simulation runs.
3. OPF 1 class 1 systems are only launched when a set of possible targets are identified, i.e., they will not be launched before ZBDs drop ramp and infantry disembarks. It is assumed that OPF 1 class 1 is not capable of destroying a ZBD with its fragmentary warhead. Anti-armor effects of OPF 1 class 1 UAS are unknown to the author.
4. The Marine Company has a restricted operations zone (ROZ) over their positions that enables the clearance and employment of UAS at the company level. Individual UAS operators act within a set of engagement criteria and priorities of fire to govern UAS employment. The MLR is operating in a distributed manner and the company does not have time to clear all its actions with the parent battalion or may not have communication with the parent battalion.

Other Assumptions:

1. The sea state and weather are permissible for amphibious operations.

IV. DESIGN OF EXPERIMENTS

EABO complement the Navy's Distributed Maritime Operations Concept and will inform how we approach missions against peer adversaries.

—38th Commandant

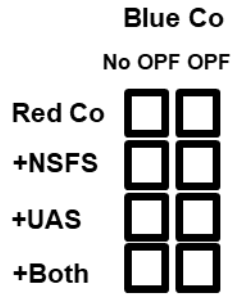
This chapter examines the experimental design process and its implications for experimental results. Specifically, it illustrates the building of a nearly orthogonal Latin hypercube to examine low correlation main effects with metamodeling.

A. CONCEPT OF EXPERIMENTATION

Experimentation began after internal verification and validation of the model. To conduct internal verification and validation, 30 independent model runs were conducted on the base model. Output data was examined to find errors in weapon to target matches or any undesired behavior in different agents. If undesired behavior was discovered, modifications were made to the model, and another 30 replications were conducted. This iterative process continued until the model required no additional modification. Once internal verification and validation was completed, experimentation began. Experimentation was sequential, with each experiment building off the previous one. A total of 44,500 simulated battles were conducted across three experimental sets from 445 total design points.

Experiment 1, the base case, conducted 100 repetitions of one design point consisting of the base model. The base model included all layers of the model for both blue and red forces, i.e., red naval surface fire support and attack UAS supporting the mechanized red company against the blue company with full OPF capabilities.

Experiment 2, threat assessment analysis, examined eight design points. The design points turned off and on different capability sets for both red and blue force. The purpose of Experiment 2 was to examine the relative effects of the different capabilities. Figure 19 shows the eight different design points which explore the different capability combinations that characterize the battle.



Experiment 2

Figure 19. Experiment 2 Design

Experiment 3 examined 436 design points. One-hundred independent replications were conducted for each design point for a total of 43,600 simulated battles. The purpose of Experiment 3 was to examine key factors discussed in the factors and levels section below to inform commanders on favorable technical requirements and favorable techniques, tactics, and procedures.

The progression of experimentation can be seen in Figure 20, which shows how the depth and breadth of experimentation increased as the author explored the model outcomes.

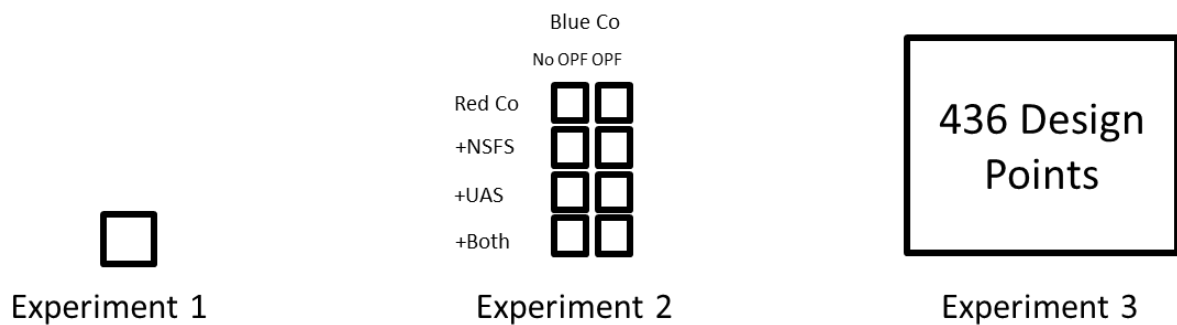


Figure 20. Overall Experimental Design Process

B. FACTORS AND LEVELS

To select factors, an extensive examination of infantry force design planning documents was conducted to understand key concerns from operational units. These concerns encapsulated unknowns about new and emerging technologies that are not yet integrated into conventional Marine infantry formations. Additionally, unknowns existed on model input parameters such as communication latency, which are more influenced by human procedures yet to be refined, not undeveloped technologies.

Experiment 1 varied no factors. It sought to understand the natural variation inherent in the base model and its corresponding parameters. Experiment 2 varied force design to examine different force mixes for both the red and blue force. No weapon parameters or other factors were varied, just whether the capability was included or not. The eight design points of Experiment 2 are illustrated in the table below. “T” indicates “true,” that the capability indicated is included in the scenario for that design point. “F” indicates “false,” that the capability indicated was not included in the scenario for that design point.

Table 2. Experiment 2 DOE

DP	Blue Infantry	Blue OPF	Red Mech Co	Red UAS	Red NSFS
1	T	F	T	F	F
2	T	F	T	F	T
3	T	F	T	T	F
4	T	F	T	T	T
5	T	T	T	F	F
6	T	T	T	F	T
7	T	T	T	T	F
8	T	T	T	T	T

Experiment 3 varied a variety of factors. In general, these factors fell into two categories: equipment and TTPs. These factors can be visualized in bins as shown in Figure 21 below.

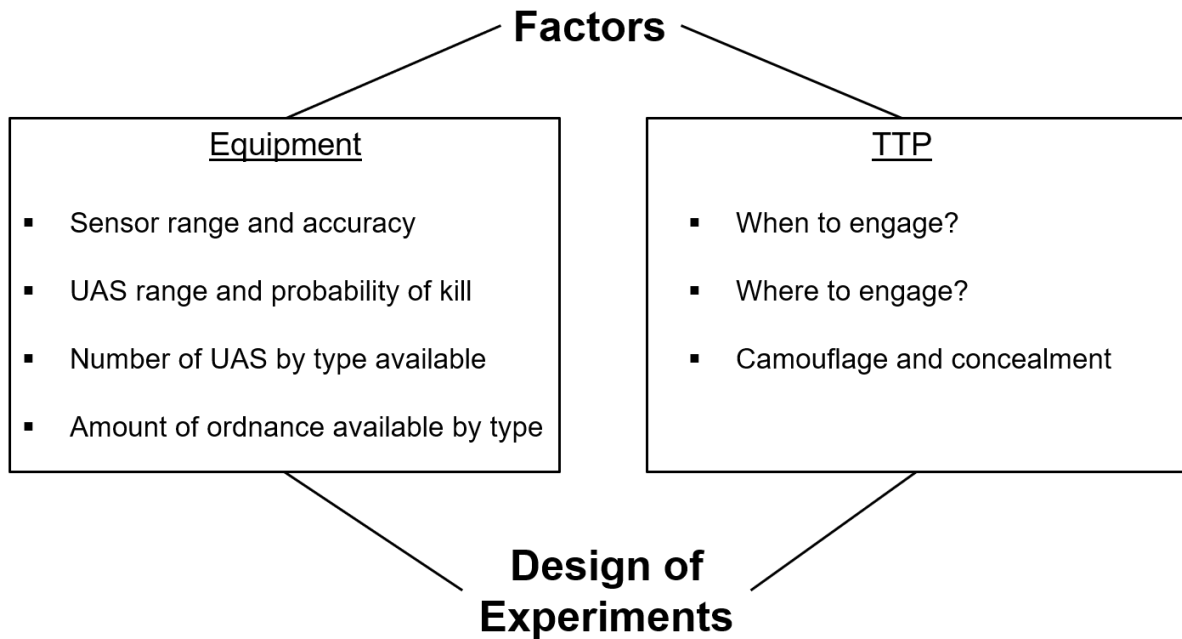


Figure 21. Factor Selection

After examining the possible factors to be explored, a subset was selected to enable high fidelity on key issues. These factors are summarized in the tables and descriptions below.

Table 3. Categorical Factors

Categorical Factors				
Factor Num	Factor Name	Factor Type	Levels	Notes
1	Red UAS	Binary	On or Off	
2	Red NSFS	Binary	On or Off	

The two categorical factors selected are red UAS and red naval surface fire support. These two support capabilities enable red force maneuver. These two factors were selected to better examine the interaction of these capabilities on the red force kill web. By including these, interactions with blue force characteristics can be examined to inform fires priorities at the battalion and MLR level attack guidance matrices.

A variety of discrete and continuous factors were used to examine the blue force under different conditions. These factors all relate to the “sensor-shooter” paradigm described in the first two chapters. Key factors include latency in the kill chain to examine how closing the loop at different speeds to kill the enemy enables battlefield victory. UAS characteristics such as swarm size, number of waves, and probability of kill were examined to determine favorable parameter mixes. Investigating these UAS attributes enable recommendations to testing agencies and wargaming professionals on force requirements. MAAW probability of kill was examined as the efficacy of the weapon system was unknown to the author, and testing data not readily available. By varying MAAW probability of kill, sensitivity analysis can be done to understand how important this squad level anti-armor weapon is to mission success. Finally, engagement distance was examined to understand the trade-off between HAW-MAW-LAW and massed surprised fires as tactics to be employed by the blue force. To accurately model this, engagement distance was tied to the OPF availability times. OPF 1 class 2 UAS squads were activated in sequence. The earlier they are activated, the sooner they could attack the red force. By controlling when these agents are active, and making them active later, different engagement distances were be tested. The discrete and continuous factors explored are summarized in Table 4.

Table 4. Discrete and Continuous Factors

Discrete/Continuous Factors				
Factor Num	Factor Name	Factor Type	Levels	Notes
1	Latency	Continuous	0-240 time-steps	Agents: CO HQ, Intel/Fires Cell, PLT HQ
2	UAS Swarm Size	Discrete	1-4 OPF 1 Class 2	Agents: Blue Med UAS 1-10
3	UAS Swarm Waves	Discrete	1-10	Agents: Blue Med UAS (active or not)
4	UAS p_kill	Continuous	.4 - .95	Agents: Blue Med UAS (med warhead)
5	MAAW p_kill	Continuous	.1 - .7	Agents: Blue FTs (MAAW weapon)
6	Blue Concealment	Continuous	0 - .9	Agents: Blue Infantry
7	Blue Engagement Distance	Continuous	0 – 15km	Agents: Blue Ground Sensors

C. NEARLY ORTHOGONAL AND BALANCED DESIGN

To examine the above factors using the model, the author used a nearly orthogonal and balanced experimental design (Vieira et al. 2013) that facilitates a robust analysis (Sanchez and Sanchez 2020). The design the author used was developed using the evolutionary algorithm in *Second Order Nearly Orthogonal Latin Hypercubes for Exploring Complex Stochastic Simulations*, by MacCalman, Vieira, and Lucas (2017). First, a 45-design point, nearly orthogonal and balanced design was constructed using a nearly orthogonal Latin hypercube for continuous factors (Cioppa and Lucas 2007). This hypercube was then combined with a 64-design point resolution V fractional factorial to add corner points. The resulting 109 design points were then crossed with a 2×2 full factorial design of the categorical factors. The result is an experimental design with 436 design points. The maximum absolute pairwise correlation between continuous variables in the design is 0.0007. Correlation between continuous variables and the space-filling properties of the design is illustrated in Figure 22.

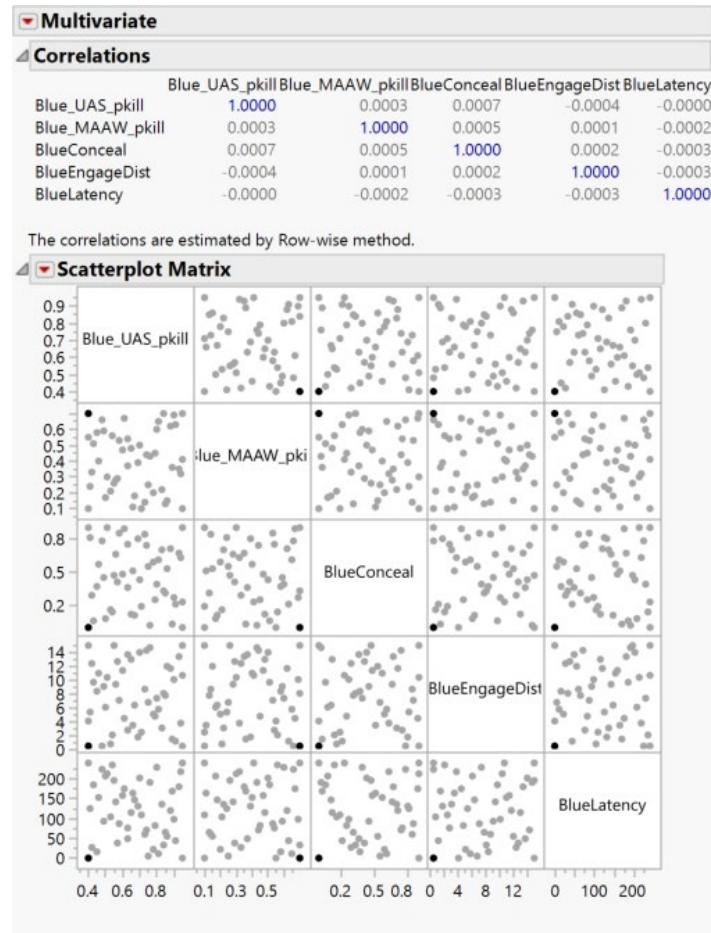


Figure 22. DOE Maximum Pairwise Correlation

From Figure 22, the space-filling properties of the design and addition of corner points using the partial fractional factorial design are illustrated. With the maximum absolute pairwise correlation being so low, confounding effects are mitigated. More information on the design can be found in appendix A.

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V. DATA ANALYSIS AND EXPERIMENT RESULTS

All of our investments in data science, machine learning, and artificial intelligence are designed to unleash the incredible talent of the individual Marine.

—38th Commandant

This chapter examines the output data from all three experiments using visual and statistical analysis and metamodeling to understand key drivers, interactions, and threshold points of the experiment factors and additionally provides evidence for force design recommendations.

A. JMP PRO AND ANALYTIC METHODS

To conduct analysis on the model results, the author applied a series of methods and tools. The two tools used to conduct analysis are JMP Pro and the R statistical programming language. JMP Pro is a suite of predictive analytics software (*JMP Pro*, 2021). R is a common programming language used for statistical analysis (*R: The R Project for Statistical Computing*, 2021). Each tool provided certain functionality and flexibility.

Key techniques used for analysis are multiple linear regression, stepwise regression, partition trees, and random forest machine learning. These techniques enabled an understanding of critical interactions in the model of interest to warfighters and drove the author's recommendations.

B. STOCHASTIC VARIABILITY OF REPRESENTATIVE SCENARIO

The model used in this research is stochastic in nature and therefore exhibits variability at each design point. This variability is captured by running the simulation with different random seeds, with all other inputs held constant, to assess how much pure randomness contributes to the variability of model outcomes. To assess the stochastic variability of the model, 100 independent replications of the base case were conducted. The data collected demonstrates quantitatively the stochastic variation possible in the combat scenario. The model variation is demonstrated via experiment 1.

C. ANALYSIS AND RESULTS OF EXPERIMENT 1 BASE CASE

Experiment 1 examined the base model with default parameter inputs. To examine the base case, 100 independent replications were run. Key outputs the author assessed to understand stochastic variability include total blue force casualties, total red ZBDs destroyed, and probability of blue victory. Each of these outcomes is summarized in the below figures.

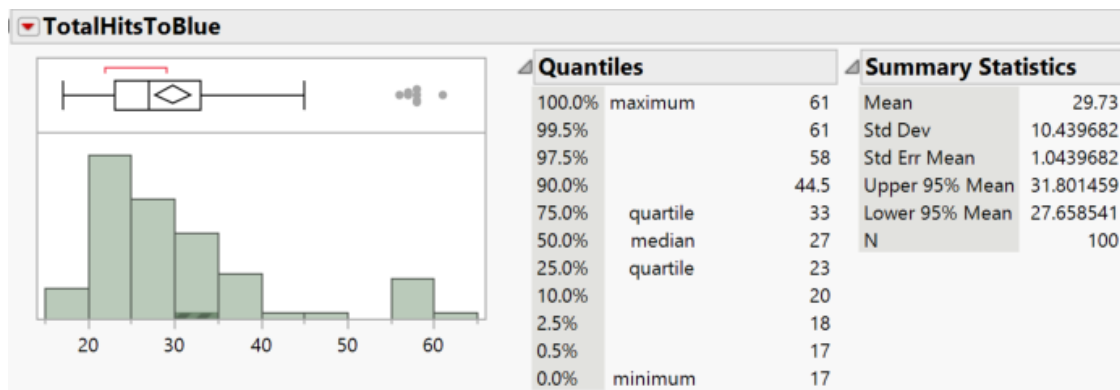


Figure 23. Experiment 1 Blue Force Casualties

As seen in Figure 23, there is significant variation in the number of blue casualties over the 100 simulated battles. The minimum number of blue casualties is 17 while the maximum is 61. There are a total possible number of 181 blue casualties. The variation in this MOE is due to the inherent randomness in conflict. The red force possessed attack UAS, naval surface fire support assets, and the red infantry company's organic weapon systems such as the 30mm ZBD cannon. For the blue force, a missed MAAW shot early in the battle, or a UAS that malfunctions can have big implications later. Imagine a situation where a ZBD is not destroyed in the water and is able to make landfall. That ZBD may during subsequent engagements find and destroy an entire squad of blue force Marines. This outcome demonstrates why getting small things such as a rocket battle drill right are so critical to the greater fight. This variability is similarly seen in Figure 24 below, which examines ZBD casualties.

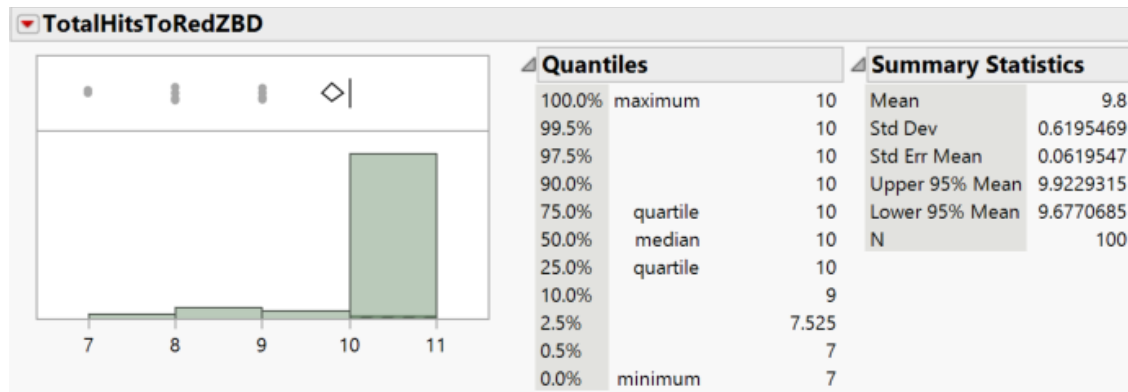


Figure 24. Experiment 1 ZBD Casualties

In the preponderance of simulated battles, the blue infantry company destroyed all 10 red force ZBDs. The kill assets included MAAW anti-armor rockets, javelin missiles, and OPF 1 class 2 UAS. Even with all these assets, the red force still wins certain engagements. Seen below in Figure 25, the blue force won 89% of the battles in our base case scenario. Victory, as discussed in previous chapters, is defined as the blue force preventing the red force from establishing a blocking position on the coastal highway. If any red forces remain on the objective by the end of the battle, the blue force loses. As a DOD doctrinal tactical task, the blue force must “control” the key terrain.

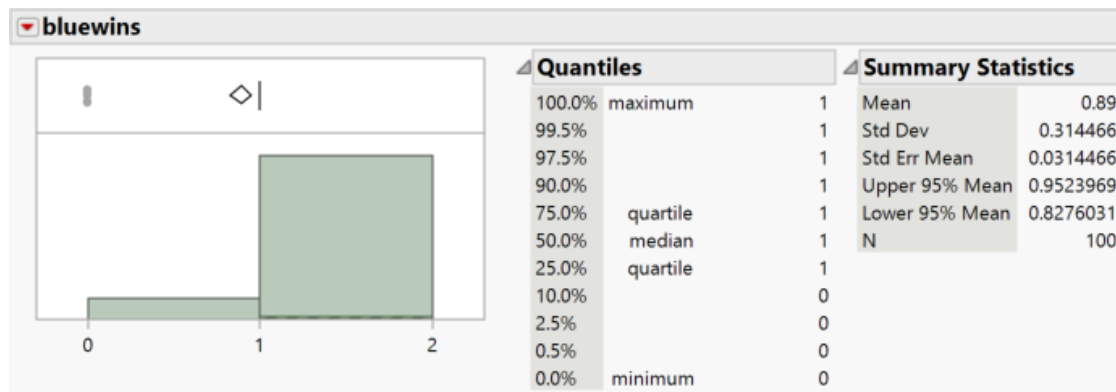


Figure 25. Experiment 1 Blue Probability of Victory

The base case, in which blue had access to significant numbers of OPF systems, is generally favorable to the blue force. The 95% confidence interval for probability of blue

victory ranges from 82.8% to 95.2%. While not a guarantee, these outcomes are on the favorable side of the risk curve for blue forces, even with the large potential for casualties. From this base case, the high attrition nature of the future battlefield is evident. Even with blue winning in the model, it is probable that almost an entire platoon will be lost. From watching scenario playbacks, it is clear that precision loitering munitions drive these outcomes, as they enable a faster and more lethal kill chain for both sides in the battle.

D. ANALYSIS AND RESULTS OF EXPERIMENT 2 RELATIVE THREAT COMPARISON

Experiment 2 explored the effects of Blue OPF and Red UAS and NSFS on the outcome of the simulated battles. For Experiment 2, 100 replications of eight different design points were run, for a total of 800 simulated battles. For design points one through four, the blue force did not have OPF capability. For design points five through eight, the blue force did have OPF capability. The survivability of the blue force is illustrated in Figure 26.

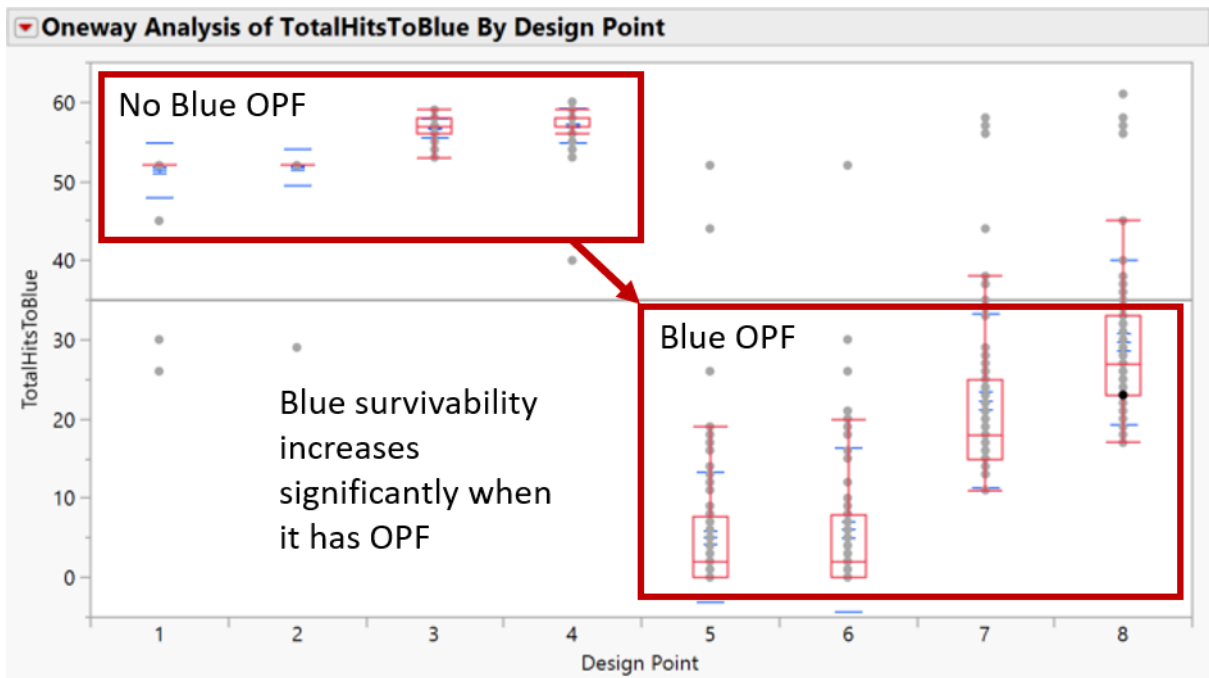


Figure 26. Experiment 2 Blue Force Survivability

In Figure 26, there is a distinct difference between the first four design points and the last four design points. When the blue force does not have OPF, it takes significantly higher numbers of casualties, about a third of the company. When the blue force does have OPF, in design points five to eight, it takes significantly less casualties, i.e., is much more survivable. It is also worth noting that there is much more variability when blue has OPF. The difference in the two outcomes is due to the standoff capabilities of the OPF systems. OPF enables the blue force commander to attrite the enemy before the ZBDs reach direct fire range and can engage the blue force. This trend is especially true when engaging ZBDs in open water. ZBDs cannot gain cover or concealment and are extremely vulnerable at sea. Because they are only moving 3–5 knots in the water, the blue force achieves catastrophic kills in which both the ZBD and any infantrymen it is carrying are killed or rendered combat ineffective. The difference between design points 5/6 and 7/8 are the addition of red force attack UAS. In design points 7 and 8, the red force possesses attack UAS swarms that they can use for both reconnaissance and engagement of the blue force. From the graphic, the great increase in casualties is apparent. The positive effect of OPF on blue force outcomes extends to their lethality, shown in Figure 27.

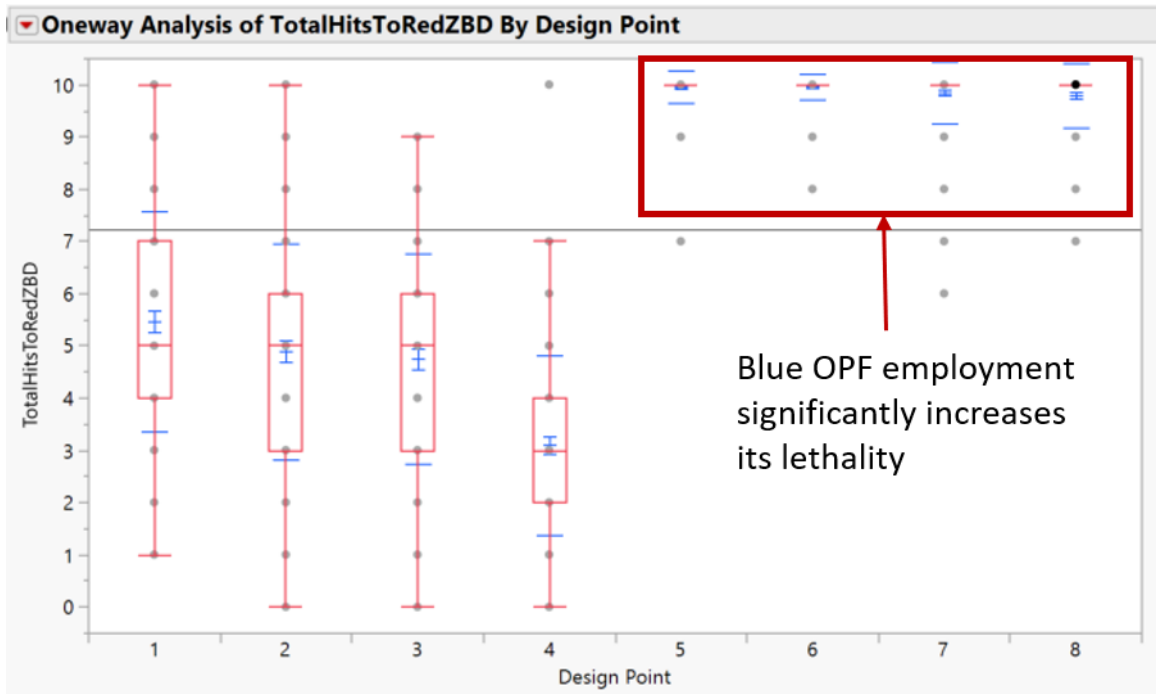


Figure 27. Experiment 2 Blue Force Lethality

When the blue force has OPF, the number of red ZBD casualties increases significantly. Additionally, the variation in ZBD casualties decreases. This outcome is important because it demonstrates the lethality gains that stand-off loitering munitions achieve, and the decrease in risk. When the blue force commander does not have OPF, the probability of destroying all 10 enemy ZBDs decreases substantially, and victory is uncertain. When the blue force commander does have OPF, the paradigm shifts. Victory is much more likely with less variance in outcomes. This trend is reflected in the probability of victory for the blue force shown in Figure 28.

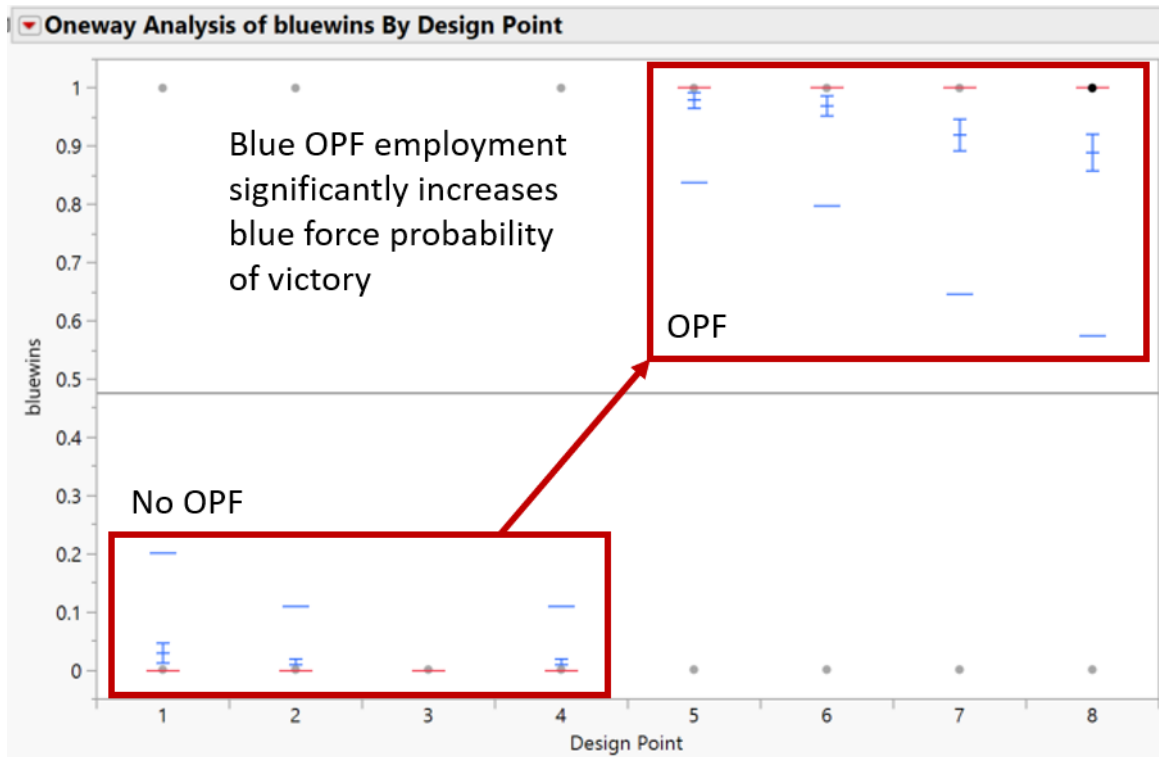


Figure 28. Experiment 2 Blue Force Probability of Victory

When the blue force does not have OPF, the probability of victory is extremely low. Due to the need to disperse forces, the blue force commander cannot mass enough combat power without OPF. The ability to mass loitering munitions at the decisive point is therefore critical to victory.

To assess the relative threats from red naval surface fire support and attack UAS, partition trees were created for blue casualties, red ZBD casualties, and blue probability of victory. Figure 29, below, examines blue casualties and provides evidence of the risk to force by different enemy assets. The risk to force is strongly linked to the survivability of the force because this is a combat scenario where casualties are being taken due to red force action. The partition tree analytic method examines the importance of different factors on model outcomes. For this specific partition tree, the R-square is 0.89. This number represents the proportion of variance in the simulation explained by the metamodel. An R-square of 0.89 indicates a strong metamodel fit on the simulation data.

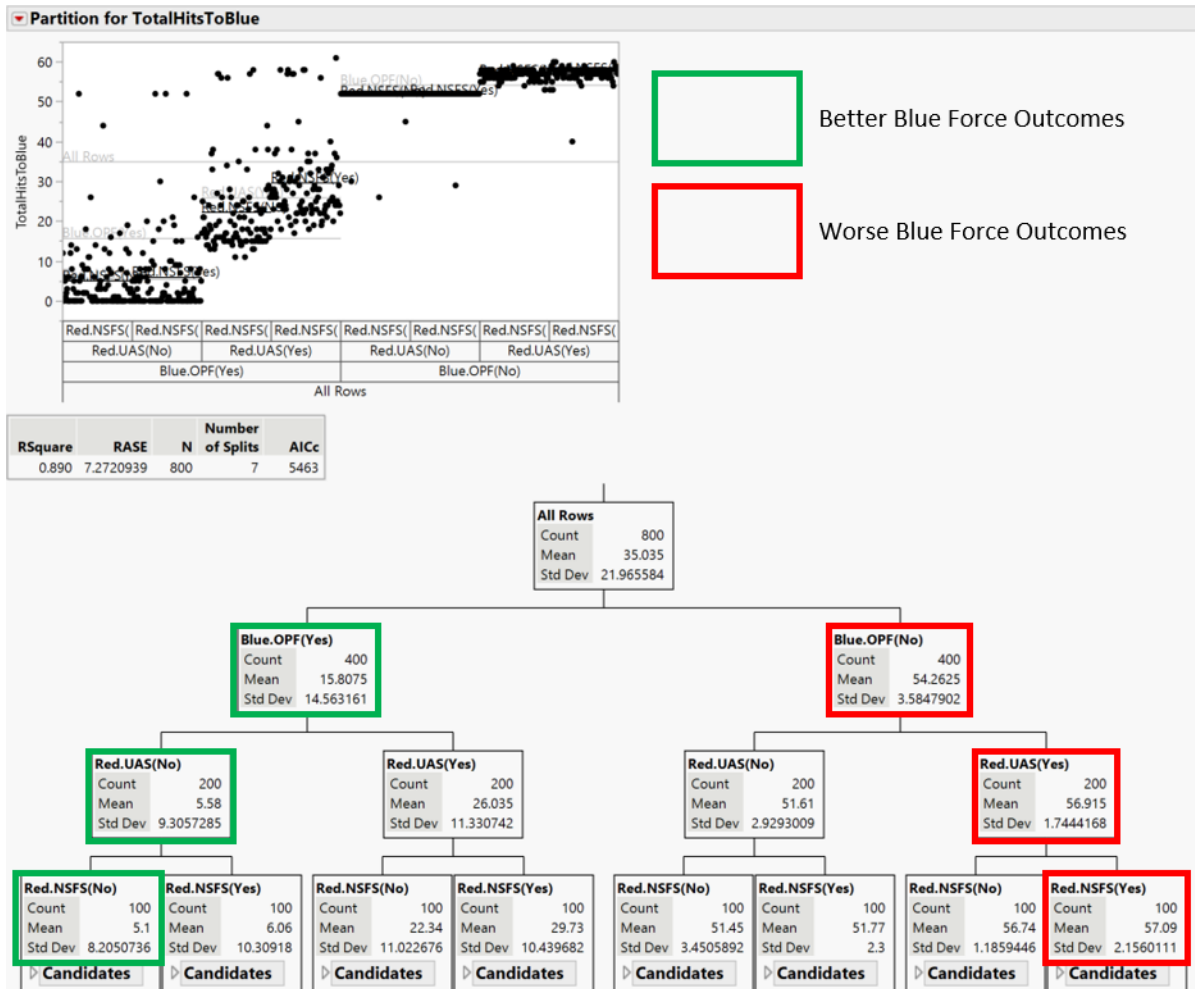


Figure 29. Experiment 2 Blue Survivability Partition Tree

The first split in the tree is on blue force structure. If blue possesses OPF, then the expected number of blue casualties is 15.8 in an engagement with red. If blue does not possess OPF, the expected number of casualties in an engagement is 54.2. This staggering difference is powerful evidence in support of a strong OPF capability at the company level. Lack of OPF systems make the future infantry company much less survivable and greatly increase the risk to force when defending against an amphibious assault.

The second level of splits in the partition tree is on whether the red force has its own OPF systems. On the left side of the tree, if the red force has UAS, the expected number of blue casualties increases from 5.6 to 26.0. On the right side of the tree, if the red force has UAS, the expected number of casualties increases from 51.6 to 56.9. This

difference is smaller than the left side. The difference in these outcomes is due to blue having or not having OPF. If blue has OPF, then more ZBDs are killed coming ashore. This trend means that the enemy must rely on attack UAS as kill assets instead of ZBD direct fire weaponry to compensate for landing less combat power. When the blue force does not have OPF, as in the right side of the partition tree, they lose more forces regardless of whether red has attack UAS or not. This outcome occurs because the blue force has a less diverse kill web with less capacity. Without OPF, blue is relying solely on MAAWs and javelin missiles to defeat the ZBDs. This situation is not favorable and leads to an asymmetric risk profile, i.e., high risk to blue and low risk to red.

The third level of splits in the partition tree is on whether the red force has naval surface fire support or not. Generally, if they do, the blue risk to force is higher, as expected. A key trend illustrated in the tree are outcomes when the red force has both UAS and naval surface fire support. Naval surface fire support is more effective when the red force also has UAS. In these cases, red can detect and classify targets with their UAS and call for fire from their naval surface fire support asset before the red infantry company makes landfall. The red force can then attack the remaining blue forces that are not killed by the naval surface fire support or attack UAS. This kill web enables efficient use of resources, leveraging a balance of precision and non-precision fires. Similar trends are seen when analyzing infantry company lethality using a partition tree, shown in Figure 30.

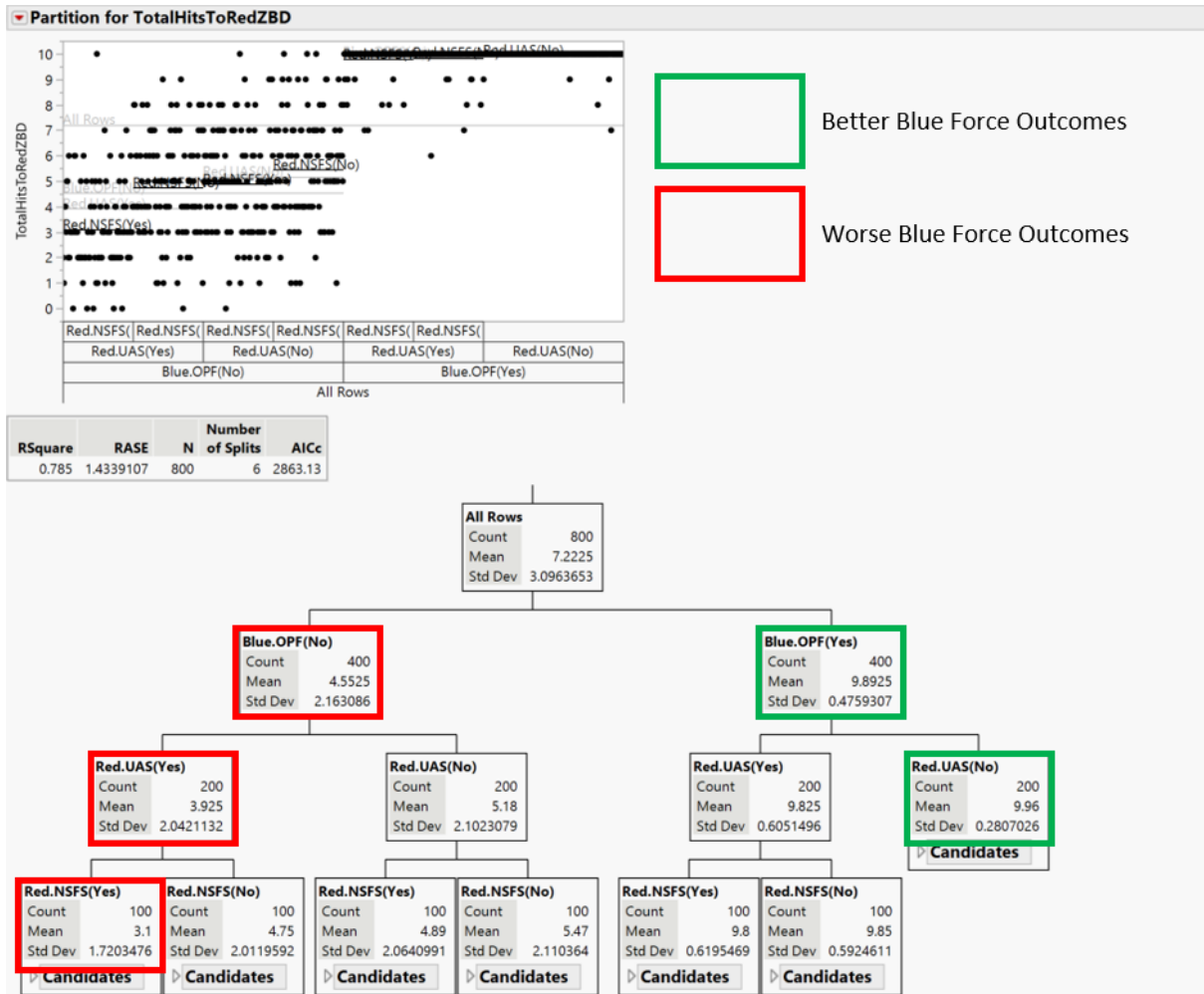


Figure 30. Experiment 2 Blue Force Lethality Partition Tree

Figure 30, the blue force lethality partition tree splits on the same factors at the same levels of the tree as does the blue survivability partition tree in Figure 29. The R-Square of 0.785 indicates a reasonable metamodel fit. The metamodel model reveals that when the blue force employs OPF, it doubles its lethality against red force ZBDs. When the blue force has OPF systems, OPF dominates the kill web as the most critical asset for the company commander. On the right side of the partition tree, the red force employment of their own attack UAS and naval surface fire support has less impact on blue force lethality. This trend means if the blue force uses OPF when red has support assets, the red force is not much more survivable. This trend is due to the ability of the blue force commander to launch OPF systems from concealment well off the shoreline. By gaining

more standoff, the search area that red must reconnoiter to find the blue OPF system increases. If the blue OPF launch points are well away from the expected red force objective, then it is less likely that they will be compromised by red UAS reconnoitering for red force maneuver. The standoff of the OPF systems also means that if the blue force platoon in vicinity of the red force objective is destroyed, then the blue force commander can still engage the red force with OPF systems and win the day. Both OPF 1 class 1 and OPF 1 class 2 UAS can be used to attack the enemy force as it attempts to consolidate on the red objective without physically maneuvering platoons. The lethality and survivability trends of the blue force drive overall victory outcomes, as shown in Figure 31.

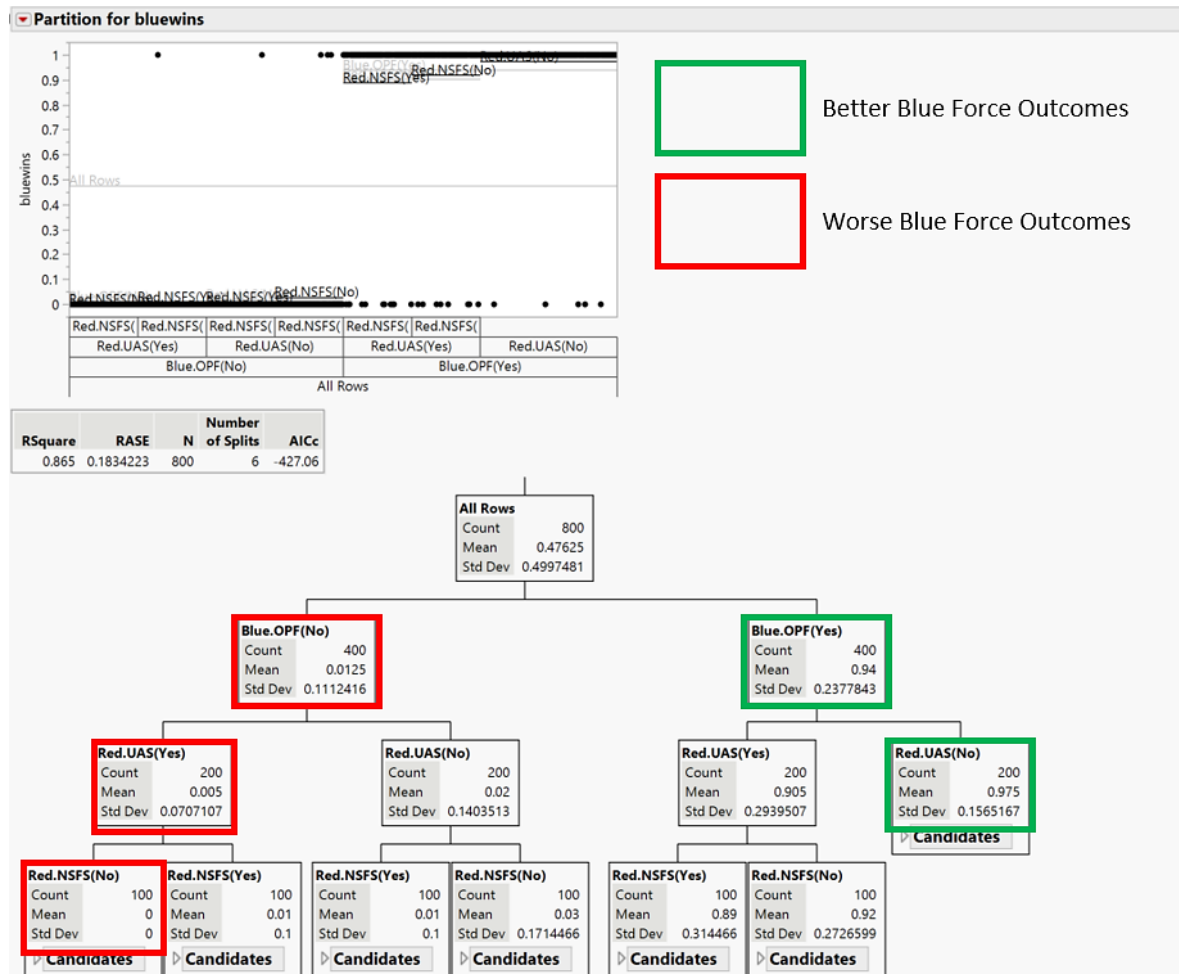


Figure 31. Experiment 2 Blue Probability of Victory

Figure 31, the blue probability of victory partition tree splits on the same factors as the previous two partition trees. The R-square of 0.865 indicates a strong metamodel fit. The probability of blue victory can be interpreted as the risk to mission. In this specific combat model, the blue force without OPF will probably lose, and the blue force with OPF will probably win. Small variation occurs if the red force also has UAS and naval surface fire support. The outcome is not much different, illustrating the dominance of OPF systems in the battle. Without OPF, the risk to mission for the blue force is extreme. In a disaggregated littoral environment, without outside support and the ability to mass direct fire weapons, the blue infantry company will not win unless it has the capability to mass loitering munitions.

E. ANALYSIS AND RESULTS OF EXPERIMENT 3 LETHALITY REQUIREMENTS

Experiment 3 examined 436 design points with 100 independent replications of each. In the 43,600 simulated battles, data was collected to better understand blue force requirements in TTPs and equipment. The experimental design enables higher fidelity insights on how the blue force can survive and win. Models were fit to the summarized data, where each design point was summarized by its mean.

1. Blue Force Survivability

The first metamodel created to understand the outcomes from Experiment 3 examined blue survivability. The measure of effectiveness of survivability was measured by number of blue force casualties in the battle. Figure 32 contains results from the stepwise regression fit, with `mean(totalHitstoBlue)` as the response.

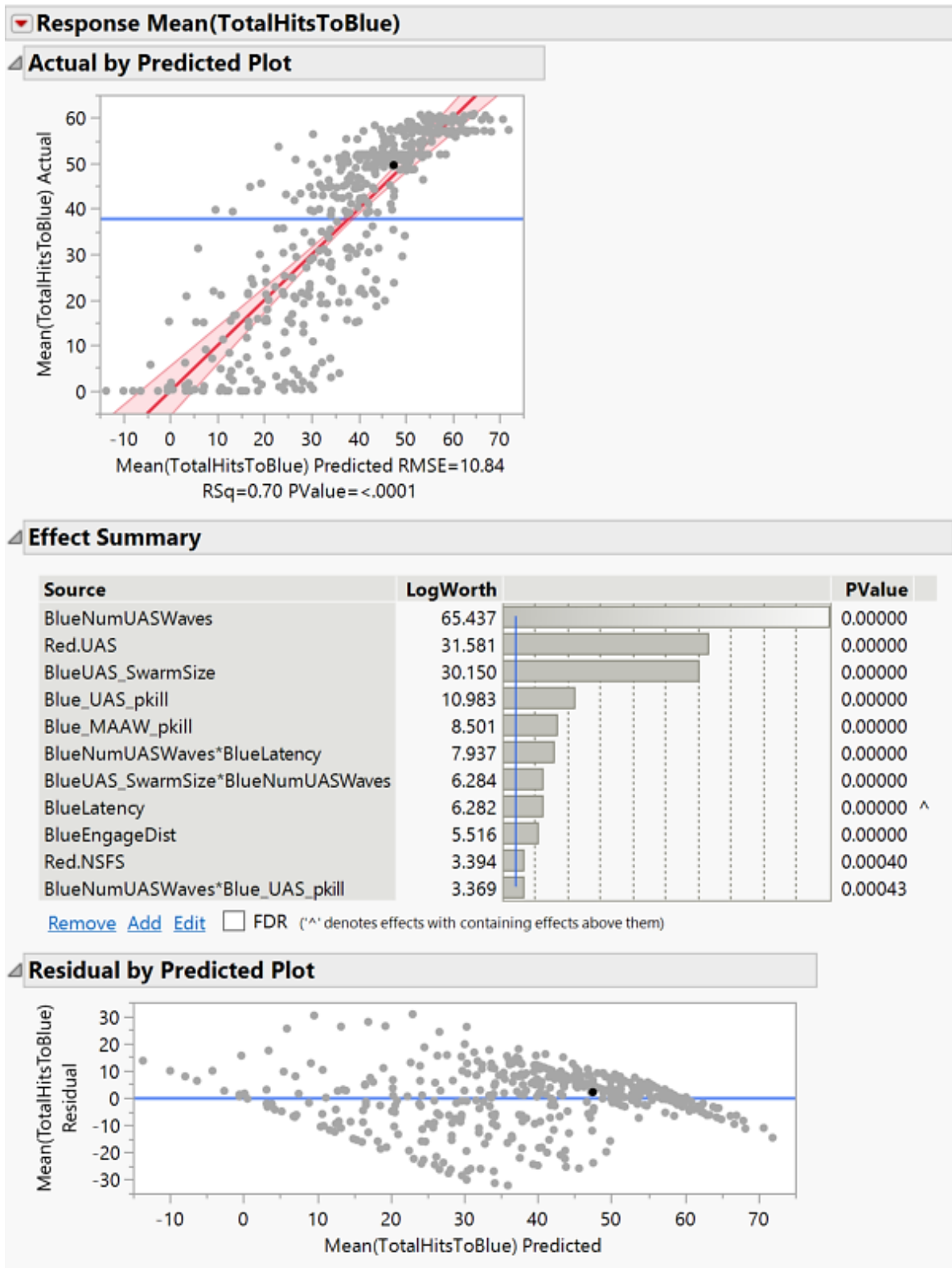


Figure 32. Experiment 3 Blue Survivability Model

From the key factors in the model, the criticality of UAS employment by both sides is clear. The survivability model has an R-squared value of 0.70, suggesting that the model achieved a reasonable fit on the data but is unable to fully capture all of the complexities of the simulation. At the bottom of Figure 32, the lack of normality in the residual plot is shown. This lack of normality is partly due to the limit in number of blue force Marines that can be engaged in the scenario. However, the model is still built on the least square's estimator, and therefore provides insight into the importance of different factors on scenario outcomes. The lack of normality means that the p-values are not precise. However, our purpose for metamodeling is to glean insight by developing readily interpretable surrogates of the simulation (Kliejnen et al. 2005).

Based on the metamodel, the blue force achieves better survivability by first employing more waves of OPF. Improving this factor can be accomplished by decreasing the time between OPF wave launches while increasing the amount of time overall that the blue company can employ UAS before it is discovered and engaged. Increased speed in UAS employment can be attained through both TTPs and equipment. UAS clearance procedures and UAS launch battle drills are both TTPs that can drastically affect how many waves the blue company can launch in the scenario. The blue company can increase the amount of time it has to employ UAS by making the UAS launch positions harder to find and engage by the red force. While direct fire engagements may occur by a blue platoon against a red force, this does not preclude the blue force from engaging with UAS. Even if a blue platoon is destroyed, the blue company UAS can still engage, if they are not co-located with the destroyed platoon and destroyed themselves. By disaggregating the blue force, survivability increases, and therefore lethality increases by allowing the blue force to engage with standoff munitions longer. Figure 33 below contains the parameter estimates of the model.

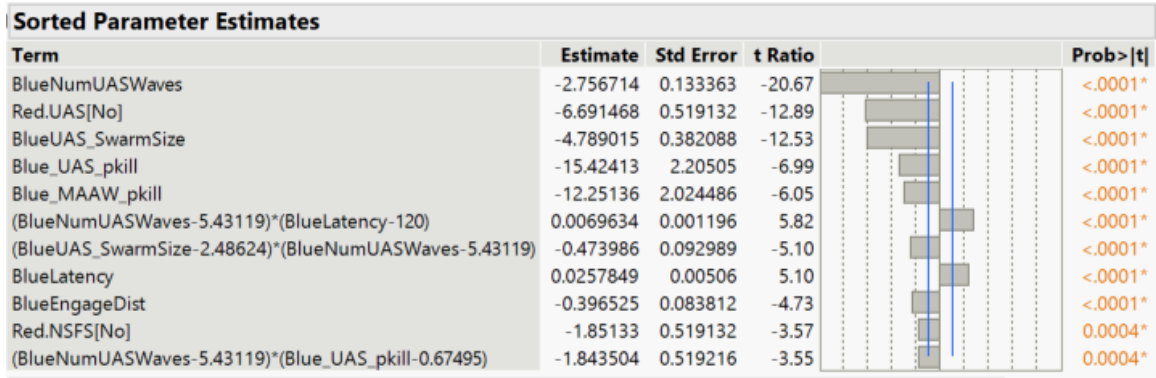


Figure 33. Experiment 3 Blue Survivability Parameter Estimates

Figures 32 and 33 illustrate the need to remove the red force ability to use UAS and increase blue force swarm size. These second and third actions by the blue force will drastically reduce casualties in the blue force and align with the warfare principle of mass. By reducing the red force's ability to mass loitering munitions, i.e., combat power, and increasing the blue force's ability to mass loitering munitions, better blue force outcomes are obtained. Finally, the survivability model suggests that HAW-MAW-LAW is superior to mass surprised fires as an engagement concept for the blue force. As engagement distance increases, blue casualties decrease. This result suggests that if blue can engage first and begin to induce friction into the red force attack, the blue force will take fewer casualties by disrupting red force kill webs and ability to synchronize effects on the battlefield.

2. Blue Force Lethality

The second metamodel created from the Experiment 3 data assessed the blue force lethality. The measure of effectiveness for blue force lethality is the number of ZBDs that the blue force destroyed. Figure 34 below summarizes the model which was fit to design point averages.

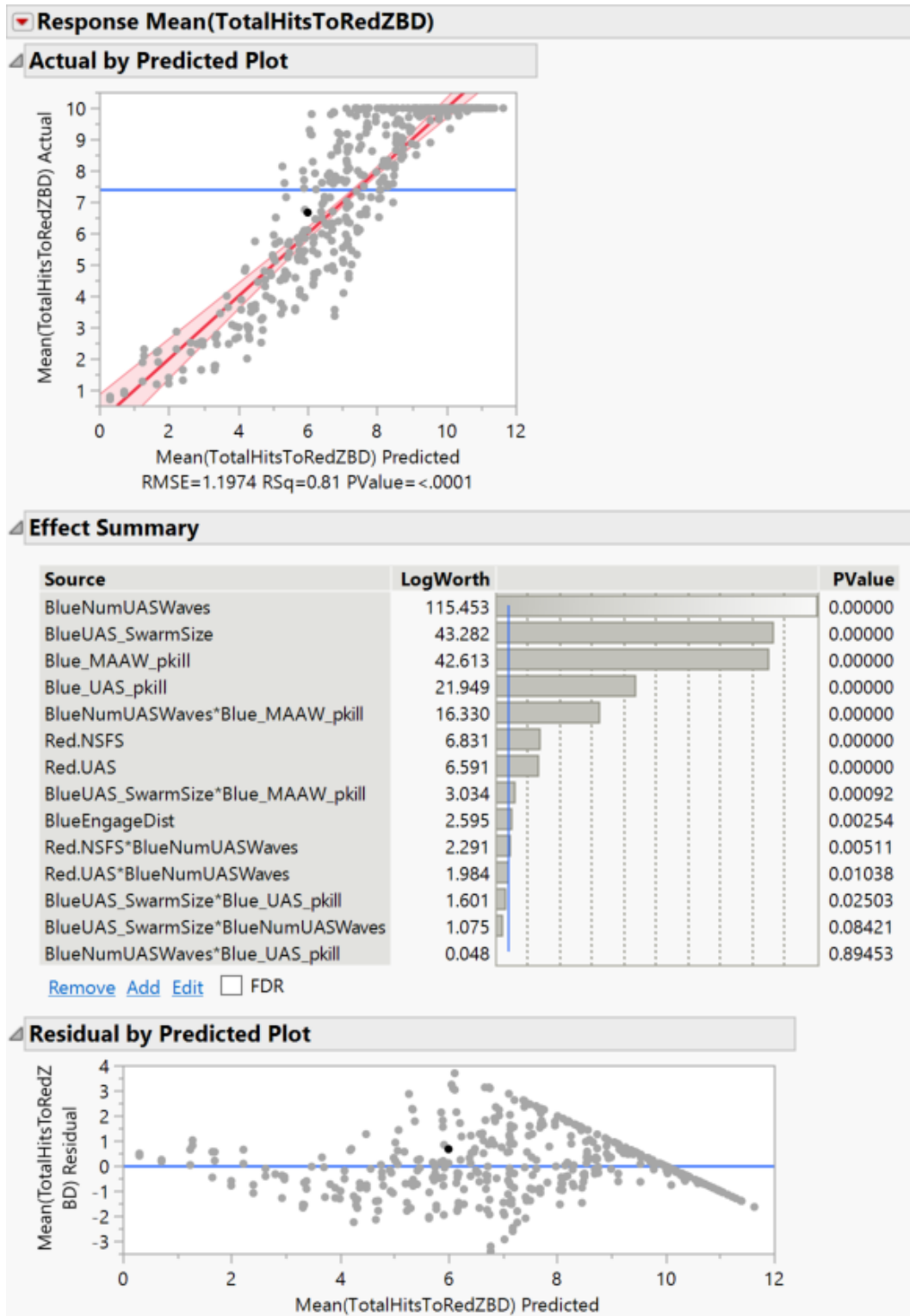


Figure 34. Experiment 3 Blue Force Lethality Model

The metamodel of ZBD casualties should be interpreted as model of the blue force lethality. The model achieves an R-Square of 0.81, suggesting a reasonable fit to the data. At the bottom of Figure 34, the lack of normality in the residual plot is displayed. This outcome, similar to the previous survivability model, is due to the limitations in number of agents that can be killed in the scenario. However, as before, the model is built on the least square's estimator, and therefore provides insight into the importance of different factors on scenario outcomes. The lethality model suggests that the most critical factors in order are:

1. Number of UAS Waves
2. Wave swarm size
3. MAAW probability of kill
4. OPF 1 class 2 probability of kill

This outcome makes intuitive sense in the context of layering kill assets within an engagement area. More loitering munitions in the HAW-MAW-LAW construct, launched early in the battle begin to attrite the enemy force. By the time the enemy force makes landfall, if it is still combat effective, squads with their MAAWs can finish destroying the remaining force. This finding aligns with missile warfare findings by Hughes and Girrier (2018) that the side that “fires effectively first” will be more lethal in the battle.

3. Blue Force Victory

The third model created with data from Experiment 3 used logistic regression to examine the probability of victory in the scenario for the blue force based upon the different input parameters. The model was fit to the design point average outcomes. The measure of effectiveness was whether the red force was able to establish a blocking position on the piece of key terrain in the scenario. The model is summarized below in Figure 35.

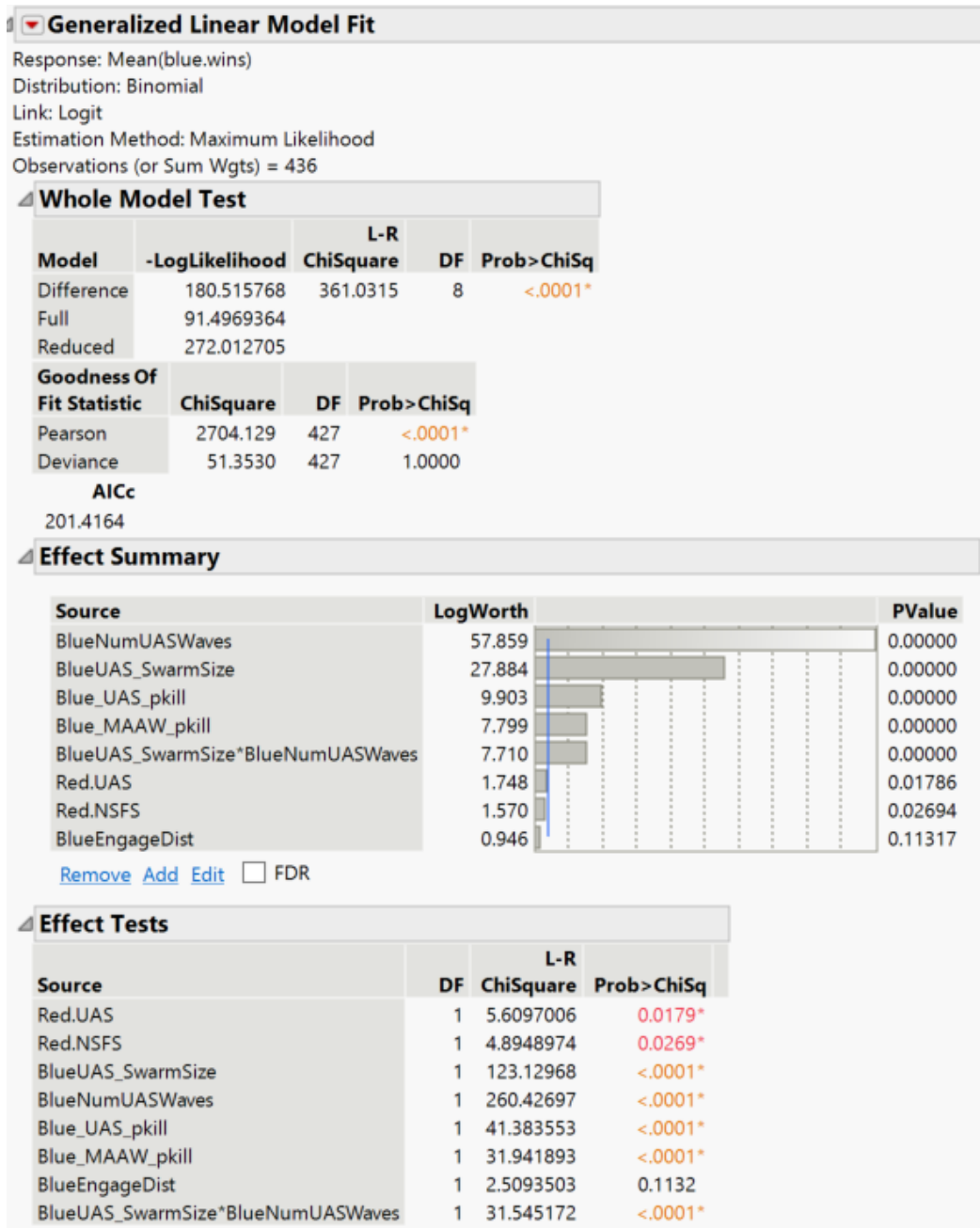


Figure 35. Experiment 3 Blue Victory Model

The victory metamodel suggests that there are a variety of requirements for blue to achieve victory. To assess those thresholds, a prediction profiler is used to examine the different parameter levels required for blue to win. Two potential outcomes are shown in Figures 36 and 37.

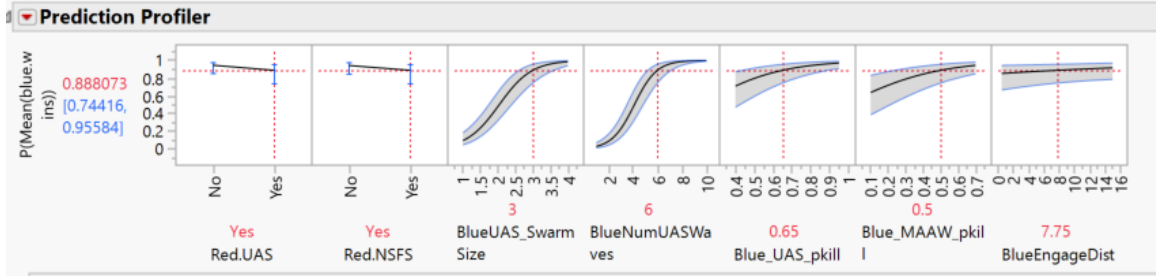


Figure 36. Experiment 3 Blue Victory Conditions Profiler 1

Figure 36 uses the victory model to assess blue force requirements if the red force has both UAS and naval surface fire support. Based upon the model, under these conditions, if the blue force can engage with six waves of OPF 1 class 2 UAS, and each wave has a swarm size of three, then the estimated probability of victory is 0.88. This probability of victory is very favorable to the blue force commander. As seen in the above figure, this outcome is predicated under a UAS probability of kill of 0.65 and MAAW probability of kill of 0.5. Engagement distance appears to matter less than these factors in the model. It should be noted though that engagement distance has a large effect on survivability, as shown in Experiment 3's model 1. If probabilities of kill greater than those shown in the profiler can be achieved, then a higher probability of victory is expected. Those probabilities were chosen in the profiler because they were conservative, and the author expects them to be achievable by a well-trained unit in combat conditions.

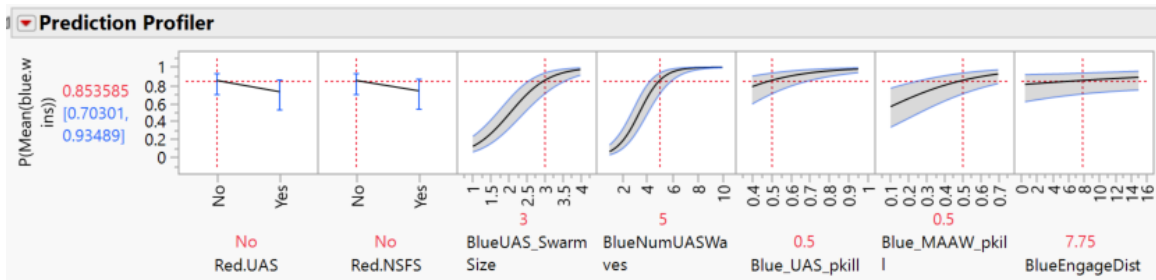


Figure 37. Experiment 3 Blue Victory Conditions Profiler 2

Figure 37 posits a scenario in which the red force does not have access to naval surface fire support or UAS. Under these conditions, the number of waves required and

probability of kill of a blue force OPF UAS can be reduced, while maintaining approximately the same probability of victory as in Figure 36. This trend is important because if the battalion and higher-level echelons above the blue force infantry company can remove the red force's ability to achieve combined arms, the amount of combat power required at blue force company level can be greatly reduced. The reduction of risk to mission by removing the red force's ability to synchronize combined arms is significant. Instead of six waves, the blue force company only requires five. Instead of a UAS probability of kill of 0.65, the new, reduced requirement is 0.5. These reduced requirements translate to fewer OPF systems being required and therefore a lighter logistical footprint.

As technology improves, there is a future potential that swarm sizes could increase to four and probability of kill for an OPF 1 class 2 system increase to 0.9. A 0.9 probability of kill is approximately the probability of kill expected of a javelin missile. Under the assumption that an OPF 1 class 2 could maintain the same probability of kill, the model suggests a probability of victory of approximately 0.93. This outcome is shown below in Figure 38.

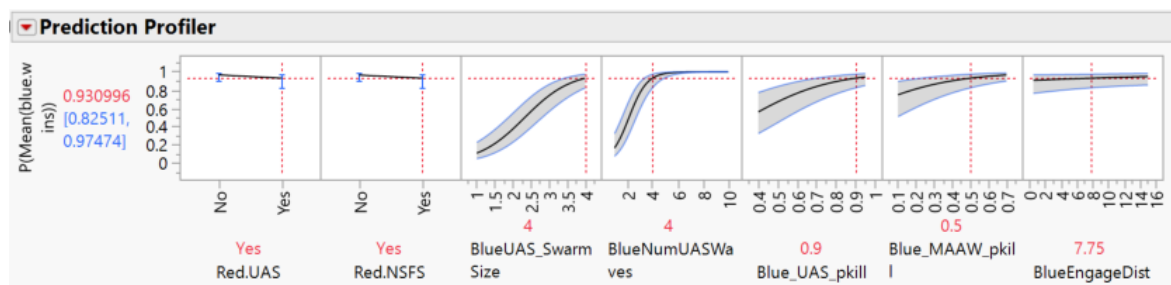


Figure 38. Experiment 3 Blue Victory Conditions Profiler 3

If the blue force can launch four UAS swarms of four systems with individual probability of kill of 0.9, this allows the blue force commander to strike with greater combat power earlier in the battle. In a littoral environment, this means more ZBDs sunk earlier, further out at sea. It is probable that catastrophic kills of ZBDs at sea lead to greater death than on land. This outcome is due to the higher probability that all red force infantry being transported on the ZBD are also killed in the UAS attack at sea. It is more difficult to egress

from a sinking ZBD at sea than a disabled one on land. Additionally, if an infantryman can escape from a burning ZBD at sea, he is most likely combat ineffective because he must be recovered and brought ashore. This recovery takes time and is unlikely in a dynamic amphibious assault. These qualitative mission planning factors combined with the quantitative factors of the model suggest that HAW-MAW-LAW and larger swarms lead to higher probabilities of victory for the blue force.

To further examine the conditions required for blue victory, a partition tree was constructed based upon the mean probability of victory for each design point. The tree can be seen below in Figure 39. This method supports the findings in the previous model and amplifies several key points.

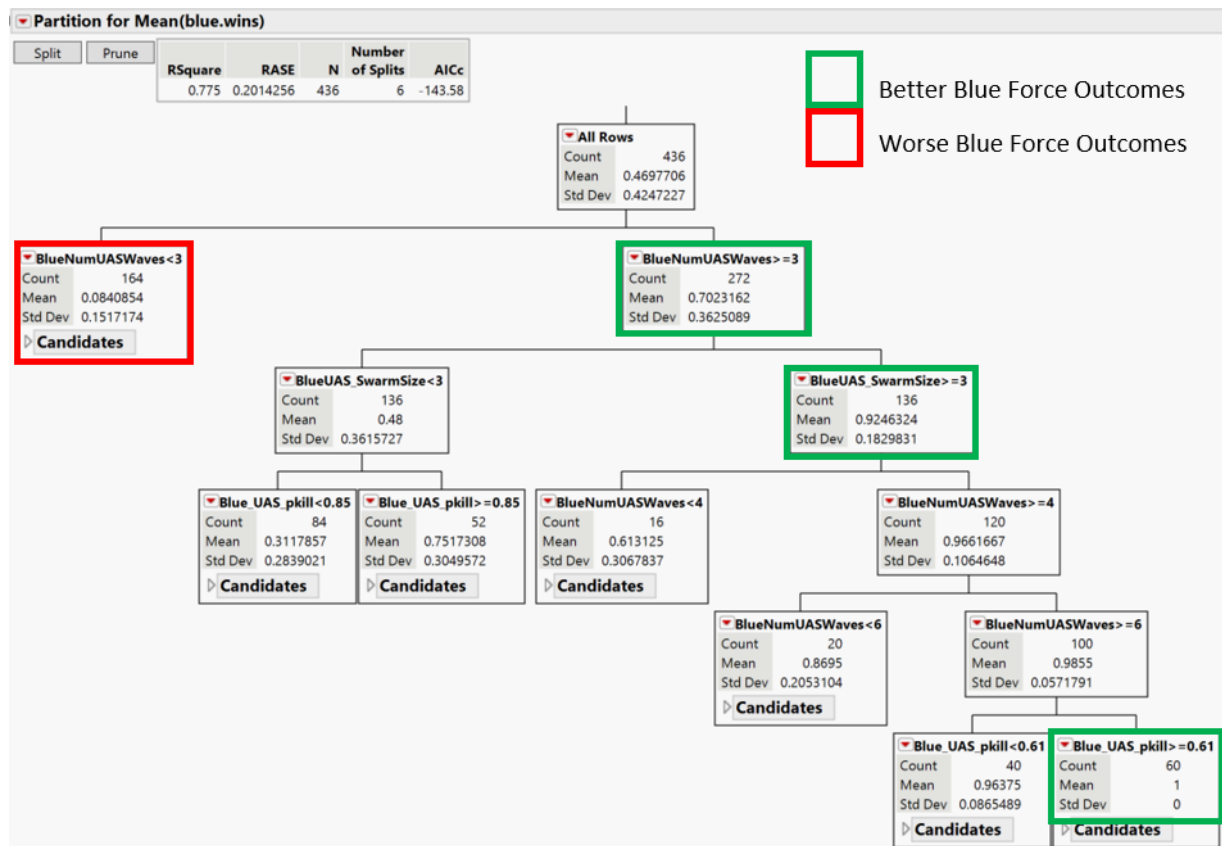


Figure 39. Experiment 3 Blue Victory Partition Tree

The partition tree suggests that the number of waves and swarm size of each wave are the most critical factors in the blue force achieving victory. The first split in the tree is on the number of waves of UAS that the blue force has available. If the blue force has three or more waves, then, on average, it wins with a probability of 0.70. If it has less than three waves, then the probability of victory is only 0.08. This difference in victory probabilities is massive just based upon this one split in the tree. The second split in the tree is on swarm size. If the blue force has three or more UAS per wave, then the mean probability of victory is 0.92. If the blue force has less than three UAS per wave the probability of victory is only 0.48. On the right side of the tree, the splits continue dividing on the number of waves of UAS the blue force can use in the battle. These continued splits suggest that there is non-linearity in the number of available waves of UAS—as was seen in the regression profiler plots above. As the blue force has access to more waves, they gain significantly larger probabilities of victory. As would be expected, as blue crosses a certain threshold, it achieves overkill in its aggregate amount of combat power, i.e., its ability to kill the enemy. Beyond a certain point, in this specific scenario, adding more UAS will not provide much higher probabilities of victory. The partition tree suggests that this threshold is six waves of three or more OPF 1 class 2 UAS. This indicates that with 18 of these UAS the blue company achieves overmatch on the red company even when the red company has supporting arms.

VI. THESIS CONCLUSION AND FUTURE WORK

We are an elite institution of warriors and will remain so on my watch.

—38th Commandant

Chapter VI summarizes key findings from this research and provides a series of targeted recommendations for different billet holders and organizations across the Marine Corps.

A. RESEARCH SUMMARY

1. Combat Modeling and Simulation

Combat modeling and simulation using robust design of experiments enabled the efficient exploration of different factors related to victory or defeat in the examined scenario. The three experiments, in aggregate, enabled the comparison of different blue and red force actions on the scenario measures of effectiveness. The analysis of scenario outcomes allows clear and actionable recommendations to commanders to reduce risk to the force and risk to the mission. While the combat models themselves are not predictive, they allow a relative assessment to identify efficient allocations of resources to different modernization efforts.

2. Metamodeling

Metamodeling was conducted on the farmed datasets from the combat model. These metamodels used different statistical techniques to understand the model outcomes. Metamodels were created to examine all three primary measures of effectiveness. Recommendations from the models themselves can be found in the next section, research findings.

B. RESEARCH FINDINGS

1. Increasing Lethality

The lethality of the blue force infantry company was measured in its ability to destroy red force ZBDs. The more lethal force was able to destroy more ZBDs earlier in

the battle. To achieve this, the blue company used both its direct fire kill assets, such as MAAW rockets and Javelin missiles, and loitering munitions, specifically OPF 1 class 2 attack UAS. The ability of the company to mass loitering munitions can be considered as its “throw weight.” Throw weight was a metric used during the age of sail to calculate the fighting power of a ship. It meant how much weight of shot a ship could engage within a cannon salvo or broadside. A modern infantry company’s throw weight is very similar and can be thought of as how many loitering munitions it can engage with. From the metamodeling, several general trends emerge.

1. More UAS in general lead to more lethality
2. Bigger swarms of UAS in general lead to more lethality
3. Fewer than 10 OPF 1 class 2 UAS being available to the blue force leads to significantly less lethality against the red force.
4. More than 18 OPF 1 class 2 did not lead to significantly greater lethality, as the blue company ran out of targets.
5. MAAWs and Javelin missiles are still important kill assets and can be critical if OPF systems are compromised or not available.
6. OPF 1 class 1 systems are useful in small numbers once red force infantry disembarks from ZBDs.

All missions, scenarios, and future operations will have different factors that require specific planning. From these above trends, however, there are several general recommendations that can be made for ordnance requirements before a company engagement.

1. Each MAAW gunner must have no less than two rockets available.
2. Each Javelin team must have no less than two missiles available.
3. The blue company has between 10 and 18 OPF 1 class 2 available as the specific mission requires.
4. Each infantry squad must have no less than two OPF 1 class 1 systems.

For comparison, a section of tanks with a combat load supporting an infantry company would have 80 main gun rounds to engage targets. If the probability of kill for each main gun round is assumed to be 0.25, then, on average, that section of tanks would be able to kill 20 targets. If the probability of kill for each OPF 1 class 2 system is assumed to be 0.90, then, on average, if the company has 18 OPF 1 class 2, it can destroy 16.2 targets. While OPF systems do not provide a protected direct-fire platform, they have a significantly greater range and the ability to indirectly engage the enemy from cover. Additionally, it is probable that 18 OPF 1 class 2 systems are much lighter and require less sustainment than a section of tanks. It is unknown to the author exactly how much cubic space 18 future OPF systems will require; however, commanders should not underestimate OPF effectiveness and its importance in killing the enemy in a conventional fight with many unknowns. Commanders should strongly consider using additional cargo space to bring more OPF loitering munitions if space is available.

While the modeled scenario focused on the company level, it would be expected that a Marine infantry company would be operating as part of a larger force, such as the MLR. Based upon the company level outcomes, several recommendations can be made to improve lethality at the company level by shaping actions at higher levels. These recommendations are specific to contesting a counter-lodgment force. If the enemy does not seek to land, then the scheme of maneuver at the MLR level should be different because it no longer needs to shape the battlefield to enable infantry company success. An example battle space shaping matrix is shown in Figure 40. The matrix is predicated on the infantry company not engaging amphibious shipping with OPF 1 class 2 UAS. It envisions a requirement for shaping fires against these targets by higher echelons.

Battlespace Shaping Matrix									
Time	Counter Lodgement Force enters MLR ASM WEZ		Counter Lodgement Force enters OPF Heavy WEZ		Counter Lodgement Force enters Company ROZ		Counter Lodgement Force makes landfall		
Pri	Prevent adversary forces from closing with EAB (ASMs)		Prevent adversary forces from synchronizing combined arms to support amphibious assault (OPF Heavy)		Block enemy amphibious mechanized elements from establishing lodgement ashore (Company Organic Fires)		Destroy enemy amphibious mechanized elements (Company Organic Fires)		
1	AD -- if friendly CAS	SAM (N); EW (N);	AD -- if friendly CAS	SAM (N); EW (N);	MN	LCAC (D); LCU (D); Mech (D)	MN	LCAC (D); LCU (D); Mech (D)	
2	FS	NSFS (N)	FS	NSFS (N)	COM	UAS Support (N); CO HQs (D)	COM	UAS Support (N); CO HQs (D)	
3	COM	UAS Support (N); TF HQs (D)	COM	UAS Support (N); TF HQs (D)	FS	NSFS (N)	FS	NSFS (N)	
4	MN	LCAC (D); LCU (D); Mech (D)	MN	LCAC (D); LCU (D); Mech (D)	AD -- if friendly CAS	SAM (N); EW (N);	AD -- if friendly CAS	SAM (N); EW (N);	
5	CSS	FS (N); Mech (N)	CSS	FS (N); Mech (N)	CSS	FS (N); Mech (N)	CSS	FS (N); Mech (N)	
Legend									
A - as acquired		EP - electronic protection			WEZ - weapon engagement zone				
AD - air defense		EW - electronic warfare							
CAS - close air support		FS - fire support							
COM - command		LCAC - Landing Craft Air Cushion							
CSS - combat service support		LCU - Landing Craft, Utility							
C2 - command and control		I - immediate							
C/B - counter battery		MN - maneuver							
CP - command post		N - neutralize							
D - destroy		NSFS - naval surface fire support							
DCA - defensive counter air		P - planned							
DF - direction finding		SACC - supporting arms control center							
EA - electronic attack		SAM - surface to air missile							

Figure 40. Battlespace Shaping Matrix

In general, the battlespace shaping matrix above advocates for initially destroying enemy air defense to enable friendly close air support and destroying naval surface fire support assets to reduce risk to anti-ship missiles. It then advocates for destroying UAS support systems as enemy shipping closes within the OPF heavy range. It is assumed for these purposes that the infantry battalion has OPF heavy systems able to destroy small ships and larger amphibious connectors such as LCACs. As the red force closes with land, OPF heavy should attrite connectors and UAS support nodes to reduce red's transport, reconnaissance, and counter reconnaissance capabilities. Finally, as ZBDs disembark off

the red force amphibious ships, the infantry company can focus on the ZBDs and prevent the enemy from establishing a lodgment ashore.

At the MLR and battalion level, the battlespace shaping matrix can be distilled into an attack guidance matrix, shown in Figure 41. The attack guidance matrix prioritizes different targets and matches weapon systems to them. If the MLR and battalion can attrite these key capabilities, the infantry company has a probability of being more successful in contesting an amphibious assault.

EVENT OR PHASE: Defense of EAB against Counter Lodgement Force						
Priority	Category	HPTs	When	How	Effect	Comments
1	Air Defense	SAM Assets, DCA Assets	P	ASM/EW	N/EW	Coordinate with EA/EP
2	UAS Support	Ships Sensors, UAS Control Nodes	I	ASM/OPF Heavy	N/EW	Coordinate with EA/EP
3	Engineer	Mine Clearing Assets	A	OPF Heavy	N	
4	Fire Support	Missile Corvette	P	ASM/OPF Heavy	N	
5	C2	Amphibious C2 nodes, SACC	A	ASM	N/EW	Coordinate with EA/EP
6	Maneuver Connectors	LCUs, Assault Support, LCACs	A	OPF Heavy	N	
7	Logistics Support	Logistics Shipping	A	ASM	N	
Legend						
A - as acquired		EP - electronic protection				
AD - air defense		EW - electronic warfare				
CAS - close air support		FS - fire support				
COM - command		LCAC - Landing Craft Air Cushion				
CSS - combat service support		LCU - Landing Craft, Utility				
C2 - command and control		I - immediate				
C/B - counter battery		MN - maneuver				
CP - command post		N - neutralize				
D - destroy		NSFS - naval surface fire support				
DCA - defensive counter air		P - planned				
DF - direction finding		SACC - supporting arms control center				
EA - electronic attack		SAM - surface to air missile				

Figure 41. Battalion Attack Guidance Matrix

Finally, at the company level, the priorities of fire should align with Figure 42. UAS and fire support should be included first if future live-fire testing shows the efficacy of company organic OPF systems against these target sets. The author envisions an OPF 1 class 2 system employed against the bridge of a ship. The shape charge explosion and corresponding spalling effect of fragmentation from an OPF 1 class 2 could be very deadly in confined shipboard spaces. Even an OPF 1 class 1 system could be effective against antennas and other sensor arrays by fragmentation damage.

EVENT OR PHASE: Defense of EAB against Counter Lodgement Force						
Priority	Category	HPTs	When	How	Effect	Comments
1	UAS Support	Ships Sensors, Control Nodes	I	OPF 1 Class 2	N/EW	Needs further analysis/live fire testing
2	Fire Support	Missile Corvette	A	OPF 1 Class 2	N	Needs further analysis/live fire testing
3	Mech	ZBDs	P	OPF 1 Class 2	N	
4	Infantry	C2; CSWs	P	OPF 1 Class 1	N	

Figure 42. Company Priorities of Fire

If OPF systems are not available in the recommended numbers, different kill assets will be required at the company level to generate sufficient combat power. The Marine Corps should examine supporting infantry companies with Amphibious Combat Vehicles (ACVs). If the vehicles have 30mm cannons and javelins integrated as part of a remote weapon system, it is possible that sufficient combat power could be generated to offset not having enough OPF systems. Additionally, ACVs should be examined as a platform for transporting and launching OPF systems. The cargo space and C2 systems in an ACV could facilitate large numbers of OPF being employed in swarm tactics. Joint light tactical vehicles could also be potential platforms for increasing company level combat power.

2. Improving Survivability

Combat modeling conducted for this thesis indicates that the future battlefield will be a highly lethal place full of precision loitering munitions. The primary method of improving blue force survivability is increasing the blue force's ability to destroy the red force before they make landfall by engaging with more UAS sooner. This trend should be seen as "use it or lose it." If the blue force waits and attempts to achieve massed surprised fires, it is probable that they will be discovered by the red force and engaged. The individual detection probability of a red UAS may be relatively small. However, with the large numbers of UAS in a small space, the smaller probabilities of detection add up quickly. It cannot be assumed that even with camouflage in prepared positions, that the blue force will remain undetected by the red force. This may not be true at larger echelons. In an MLR sized battlespace, mass surprised fires take on a different character, which is beyond the scope of this thesis.

At the company level, there are several characteristics that make survivability difficult. To contest an amphibious assault, a company must be close enough to the water

to employ its OPF systems. This fact means that there are only so many places a company can hide. If the enemy is seeking to make landfall, it is intent on committing a large amount of combat power supported by significant amounts of close air support and other fires. Because of this, even if the blue force won in the combat model, it often took large numbers of casualties. Marine Corps planners should plan for the possibility of large numbers of casualties in infantry units conducting EAB. More research should be done on this subject, examining how to conduct tactical combat casualty care in EAB and role 2 surgery to save Marine lives. Whenever a Marine platoon is discovered by a red UAS swarm, it can be engaged by the red force quickly and destroyed. The blue company may still win, however, because it is disaggregated and can still mass enough UAS from the company headquarters and other platoons.

Small actions can be taken at the company level to increase survivability of key assets. In the scenario, blue javelin teams were often destroyed by red UAS as they are a high payoff target for the red force. Because they were grouped together in the combat model, one or two red UAS often killed both members of the team. To conduct a javelin battle drill, only one 0352 anti-tank missile Marine is required. The infantry company commander should consider disaggregating 0352s into hides before the amphibious assault takes place to increase the probability that at least one 0352 survives to conduct an anti-tank guided missile battle drill. Once the enemy makes landfall or as required, the 0352s could move out of a hide and link up with their weapon system to engage enemy forces.

The company headquarters and OPF 1 class 2 launchers should be behind and offset from the platoon defenses. By moving these assets away from potential enemy objectives, it is less likely that they will be detected and targeted. Dispersion is critical in this regard. Additionally, key target indicators of UAS capability should be hidden, if possible, to reduce the probability that OPF 1 class 2 launchers are detected and classified. The enemy will know and understand that OPF capability is a high payoff target for them, and act accordingly to find and destroy it.

3. Generating Victory

To generate victory at the company level, the company commander must be enabled by the battalion to act. Permissive fire support coordination measures enable maneuver warfare. To start, the company should have a restricted operations zone (ROZ), or other fire support control measure (FSCM), which enables it to employ OPF with impunity. If the company must ask for permission every time it launches a UAS, latency will be too high, and opportunities missed. To enable OPF heavy to be employed by the battalion, an air corridor should be established, offset to the company engagement areas, to allow the battalion to provide shaping fires through the ROZ. If the corridor is not possible, the maximum altitude of the ROZ should be limited to the largest maximum ordnance of the 81mm mortar targets the company will be firing in its ROZ plus a sufficient buffer distance. OPF heavy could then be flown over the top of the ROZ. In a communication denied environment, close coordination to turn on and off a ROZ, or route through a ROZ will be difficult. Passive, permissive measures should be examined as the standard for these future operations. An example ROZ is shown in Figure 43.

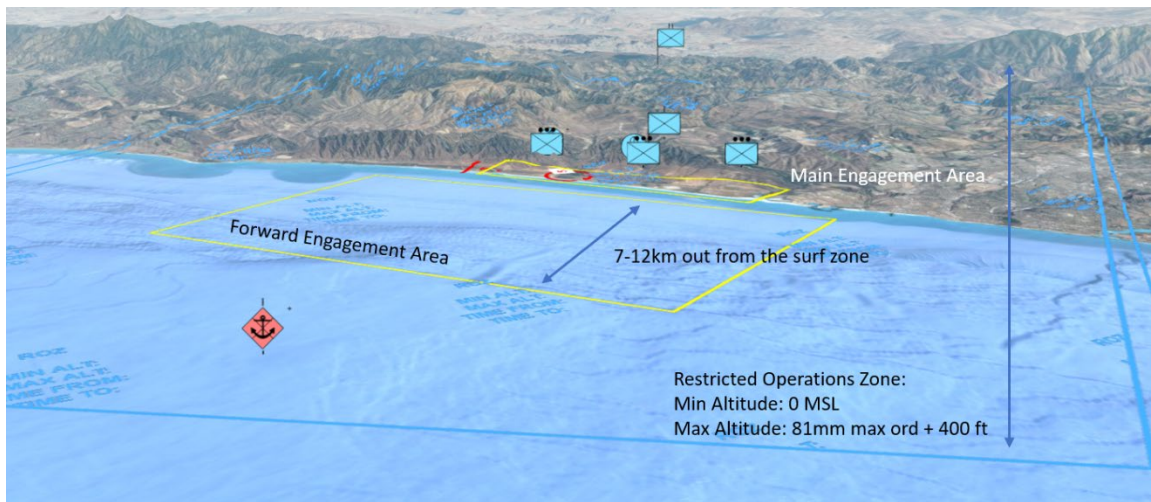


Figure 43. Recommended Company ROZ

Once the enemy enters the forward engagement area and conditions allow, the company should engage with as many OPF 1 class 2 systems as possible. If these systems

are shown to be efficacious against enemy shipping, shipping should be engaged. If not then, as soon as ZBDs disembark from the ship, the ZBDs should be engaged. The combat modeling and analysis conducted for this thesis demonstrates that ZBDs moving between three and five knots in the surf are highly vulnerable to loitering munitions. Conducting a top-down attack against a ZBD without cover or concealment could achieve a catastrophic kill where any infantry the ZBD is transporting are killed or rendered combat ineffective and the ZBD itself neutralized or destroyed. The future company commander should exploit the ZBDs vulnerability in the water and not allow it to reach the shore if possible. This concept is illustrated in Figure 44.

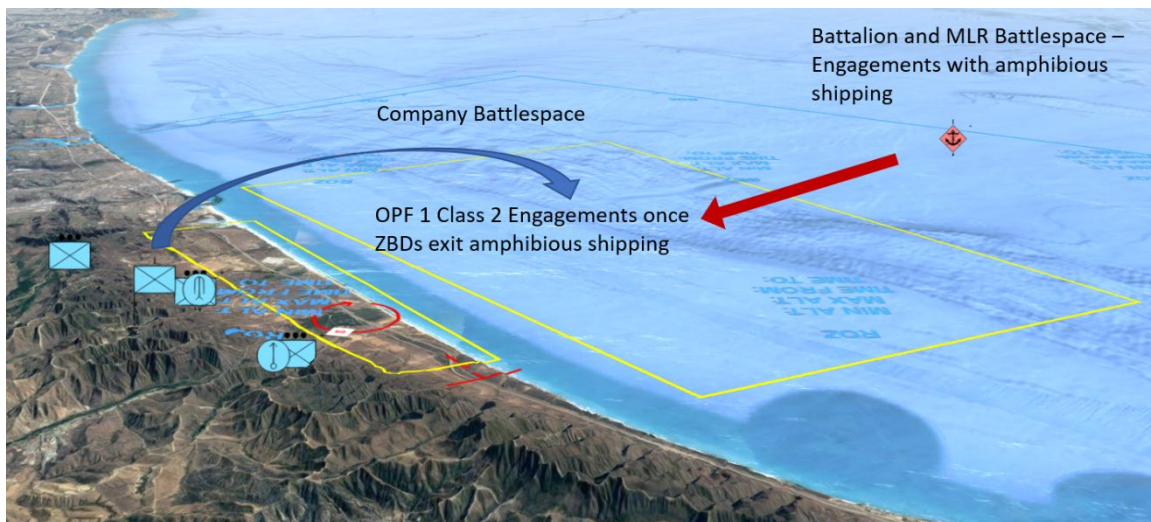


Figure 44. Recommended Forward Engagement Area

If any enemy forces are still able to make landfall, platoons can mass OPF 1 class 1 systems against disembarked red infantry forces. The blue force should hold their direct fire weapon systems until their position is compromised or a decisive advantage is gained. By adding friction and attriting the enemy systems early in the battle, it is less likely that the enemy will be able to synchronize effects for a combined arms amphibious assault. Additionally, it is probable that the red force company leadership will be killed early in the battle, increasing the probability that the blue force wins. An example of this concept is shown in Figure 45.

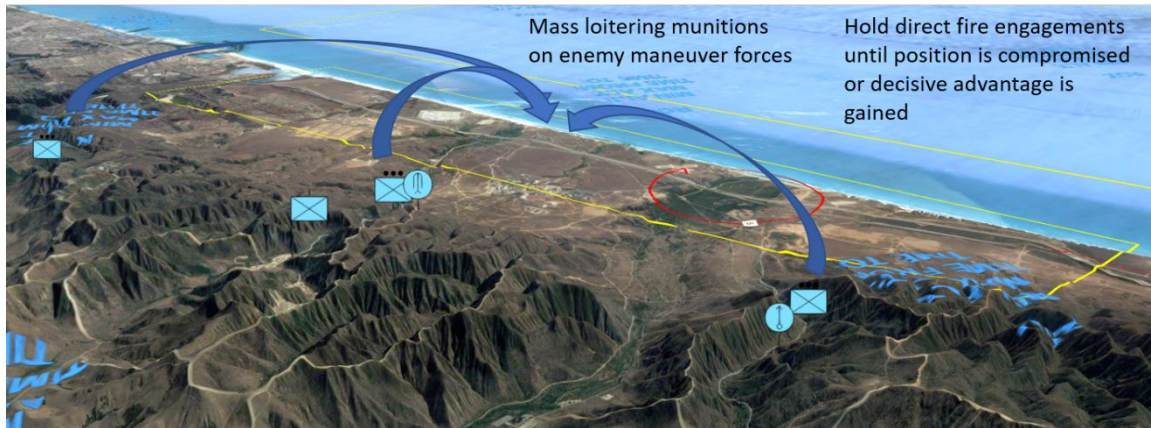


Figure 45. Recommended Main Engagement Area

C. FUTURE RESEARCH

1. Modeling and Simulation

In the EAB research space, significant future research is required to examine the many different possible scenarios, force designs, and other factors that will influence the future fight. Future modeling and simulation efforts could take the following lines of efforts:

- Anti-swarm modeling -- how will the blue force stop the red force swarms from locating and destroying key blue force capabilities before they can be used? This research did not model counter UAS technologies.
- Electronic warfare modeling -- how will electronic attack and defense be used for the reconnaissance and counter-reconnaissance efforts in EAB? This research did not model electronic warfare as it stayed at the unclassified level.
- Engineering modeling -- how will expeditionary engineering technologies enhance the survivability of the blue force?
- Refinement of the current model -- as these emerging technologies are tested and TTPs refined, the base model used in this research can be updated with more accurate (even classified) numbers. Uncertainty still

exists, especially in the reconnaissance modeling. As fields of view, convolutional-neural net edge classification capabilities, and sensor specifications become clearer, these factors could be used to update the parameters of the model.

- Use of a high-resolution model to see if the results from MANA-V are replicable in a different modeling environment.

2. Wargaming

To aid in qualitative analysis, wargaming can be conducted for both exploratory and educational purposes. The outputs of this thesis work can be used for the following purposes:

- To help company and battalion staffs in understanding the future operational environment and explore possible future TTPs associated with the OPF systems.
- To aid in understanding force requirements and adjudication of an MLR level wargame
- To assist the red cell in identifying potential weaknesses in the blue force kill web that could be exploited by enemy forces to break the blue system.

3. Live and Live-Fire Experimentation

Both live and live-fire experimentation is required to examine future operational environments and validate the assumptions of this thesis work. The scenario examined in this thesis (and subsets of it) could be tested in both live experimentation and eventually live-fire experimentation in some sort of live-fire range. This testing could be iterative and take the following steps:

- Development and testing of OPF 1 class 1 and 2 systems against light armored targets, ship sensor arrays, and other targets such as ship-to-shore connectors.

- Development and testing of OPF launch battle drills with the company headquarters element.
- Development and testing of OPF launch battle drills with the company headquarters and squad UAS operators to examine the echeloning of fires under a disaggregated company HAW-MAW-LAW employment concept.
- Full testing of a live fire disaggregated company range with direct and indirect fire weapons systems integrated with OPF.

APPENDIX A. DESIGN OF EXPERIMENTS

A. 2×2 FULL FACTORIAL

Red UAS	Red NSFS
Yes	Yes
Yes	No
No	Yes
No	No

B. NOB

BlueUAS_Swar mSize	BlueNumUAS Waves	Blue_UAS pkill	Blue_MAAW pkill	BlueCon ceal	BlueEngag eDist	BlueLate ncy
3	3	0.56	0.28	0.66	9.4	142
1	2	0.51	0.3	0.9	10.4	213
1	5	0.58	0.53	0.85	7.1	87
2	1	0.4	0.55	0	4.1	0
3	6	0.8	0.6	0.39	7.4	229
3	2	0.78	0.2	0.59	5.1	22
2	7	0.6	0.47	0.48	11.4	158
4	4	0.75	0.25	0.55	6.8	5
3	10	0.84	0.7	0.33	8.1	33
4	10	0.55	0.26	0.47	15	196
4	3	0.66	0.11	0.51	3.5	164
4	4	0.7	0.5	0.43	14	202
2	2	0.91	0.63	0.21	1.2	44
2	8	0.48	0.66	0.78	0.5	224
4	1	0.5	0.17	0.08	6.1	207
3	9	0.63	0.37	0.36	13.7	49
4	1	0.63	0.54	0.75	2.8	76
4	8	0.83	0.22	0.7	3.1	136
4	10	0.45	0.58	0.37	8.4	16
1	4	0.71	0.1	0.19	2.5	109
2	9	0.85	0.13	0.31	7.8	65
3	6	0.61	0.67	0.89	4.5	175
4	3	0.49	0.59	0.45	9.1	93
3	5	0.42	0.33	0.29	12.4	27
1	5	0.76	0.43	0.02	14.7	191
1	7	0.57	0.29	0.41	12.7	38
3	5	0.67	0.18	0.11	6.4	147

3	9	0.79	0.45	0.25	4.8	82
1	7	0.54	0.56	0.14	2.1	235
1	2	0.81	0.65	0.61	5.8	11
1	7	0.53	0.21	0.16	0.8	104
4	4	0.74	0.44	0.74	14.3	71
4	10	0.89	0.36	0.03	1.5	169
2	4	0.46	0.4	0.57	11	153
2	6	0.43	0.51	0.06	9.7	185
1	9	0.88	0.62	0.71	11.7	120
1	6	0.86	0.15	0.53	12	55
1	1	0.65	0.48	0.12	13	115
3	1	0.93	0.35	0.67	13.4	180
2	3	0.94	0.32	0.63	3.8	218
2	8	0.41	0.24	0.81	5.4	125
3	3	0.9	0.69	0.27	10.1	98
1	8	0.73	0.14	0.84	8.7	60
2	5	0.95	0.41	0.23	10.7	240
2	7	0.69	0.39	0.8	1.8	131

C. RESOLUTION V FRACTIONAL FACTORIAL

BlueUAS_Swar mSize	BlueNumUAS Waves	Blue_UAS pkill	Blue_MAAW pkill	BlueCon ceal	BlueEngag eDist	BlueLate ncy
3	3	0.56	0.28	0.66	9.4	142
1	2	0.51	0.3	0.9	10.4	213
1	5	0.58	0.53	0.85	7.1	87
2	1	0.4	0.55	0	4.1	0
3	6	0.8	0.6	0.39	7.4	229
3	2	0.78	0.2	0.59	5.1	22
2	7	0.6	0.47	0.48	11.4	158
4	4	0.75	0.25	0.55	6.8	5
3	10	0.84	0.7	0.33	8.1	33
4	10	0.55	0.26	0.47	15	196
4	3	0.66	0.11	0.51	3.5	164
4	4	0.7	0.5	0.43	14	202
2	2	0.91	0.63	0.21	1.2	44
2	8	0.48	0.66	0.78	0.5	224
4	1	0.5	0.17	0.08	6.1	207
3	9	0.63	0.37	0.36	13.7	49
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2	9	0.85	0.13	0.31	7.8	65
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1	5	0.76	0.43	0.02	14.7	191
1	7	0.57	0.29	0.41	12.7	38
3	5	0.67	0.18	0.11	6.4	147
3	9	0.79	0.45	0.25	4.8	82
1	7	0.54	0.56	0.14	2.1	235
1	2	0.81	0.65	0.61	5.8	11
1	7	0.53	0.21	0.16	0.8	104
4	4	0.74	0.44	0.74	14.3	71
4	10	0.89	0.36	0.03	1.5	169
2	4	0.46	0.4	0.57	11	153
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1	9	0.88	0.62	0.71	11.7	120
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1	1	0.65	0.48	0.12	13	115
3	1	0.93	0.35	0.67	13.4	180
2	3	0.94	0.32	0.63	3.8	218
2	8	0.41	0.24	0.81	5.4	125
3	3	0.9	0.69	0.27	10.1	98
1	8	0.73	0.14	0.84	8.7	60
2	5	0.95	0.41	0.23	10.7	240
2	7	0.69	0.39	0.8	1.8	131

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APPENDIX B. ADDITIONAL MODELING

During the analysis phase of the research, the author created over 30 different metamodels to examine the data. Not all models made it into the body of this thesis, and some are included here for readers.

The first additional model is a partition tree fit to the raw Experiment 3 outputs. The overall tree is shown in Figure 46. Figure 47 highlights the importance of latency. As latency increases in the network there is great risk to force, i.e., more blue force casualties.

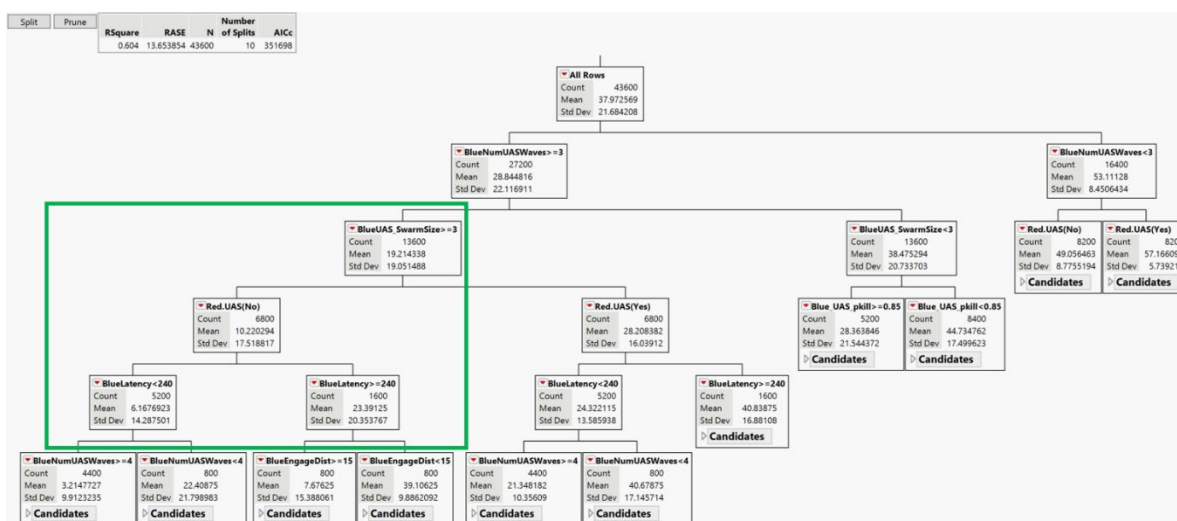


Figure 46. Experiment 3 Blue Force Survivability Partition Tree

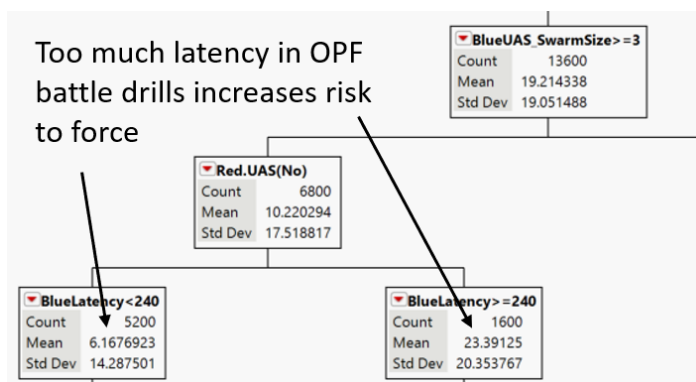


Figure 47. Latency Effect on Survivability

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