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ANALYSIS OF ARTILLERY SURVIVABILITY IN DISTRIBUTED OPERATIONS

by

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13. ABSTRACT (maximum 200 words)

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This research assesses two artillery employment tactics, battery and distributed, by designing combat scenarios in Map Aware Non-Uniform Automata (MANA). A Blue force represents the U.S. Marine Corps while the Red force models the Russian Army. The researcher uses five decision variables to represent tactical decisions faced by unit commanders to vary input values for the Blue artillery unit. An experiment uses the five decision variables to data farm the 12,900 simulation runs. JMP is used to analyze the results and assess the effectiveness of each employment tactic. Results show that distributed operations significantly increase the chance of victory and reduce the number of friendly casualties. The study concludes with a recommendation to re-evaluate current artillery doctrine and the Table of Organization and Equipment for an artillery battery.

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ANALYSIS OF ARTILLERY SURVIVABILITY IN DISTRIBUTED OPERATIONS

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AFATDS	Advanced Field Artillery Tactical Data System
AMSAA	Army Material Systems Analysis Activity
AO	area of operations
BDA	battle damage assessment
BTG	brigade tactical group
CLA	Communication-Location Assembly
CPG	Commandant's Planning Guidance
CSD	Chief of Section Display
CSV	comma-separated value
DAGR	Defense Advanced GPS Receiver
DFCS	Digital Fire Control System
DMSO	Defense Modeling and Simulation Office
DO	distributed operation
DoE	Design of experiment
DPICM	dual-purpose improved conventional munitions
DTA	Defence Technology Agency
FAS	Federation of American Scientists
FDC	Fire Direction Center
FIRECAP	fire capable
FMF	Fleet Marine Force
G/ATOR	ground/air task-oriented radar
HIMARS	High Mobility Artillery Rocket System
HMMWV	High Mobility Multi-Wheeled Vehicle
IDF	indirect fire
ITX	Integrated Training Exercise
LCAC	Landing Craft Air Cushion
LCU	Landing Craft Utility
LMG	light machine gun
MAGTF	Marine Air Ground Task Force
MANA	Map Aware Non-Uniform Automata

MCCDC	Marine Corps Combat Development Command
MCWL	Marine Corps Warfighting Lab
MERS	Marine Expeditionary Rifle Squad
MLRS	Multiple Launch Rocket System
MOE	measure of effectiveness
NOLH	nearly orthogonal Latin hypercube
NPS	Naval Postgraduate School
NRAC	Naval Research Advisory Committee
RPM	rounds per minute
SEED	Simulation Experiments and Efficient Designs
SOP	standard operating procedure
TTP	tactics, techniques, and procedures
TIP	time in position after fired upon
UAS	unmanned aerial system
USMC	United States Marine Corps
XML	eXtensible markup language

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I. INTRODUCTION

A. OVERVIEW

The U.S. Marine Corps is in the process of transitioning from counterinsurgency operations to a near-peer adversarial focus. The Marine Corps has increased its involvement in large scale exercises in Europe and altered Integrated Training Exercise (ITX) (Szoldra, 2019). Specifically, within the artillery community, the concept of survivability and mobility received additional emphasis since the Russian artillery attack against Ukrainian soldiers at Zelenopillya in July of 2014. The attack highlights the increased lethality achieved by integrating unmanned aerial systems into the indirect fire (IDF) support kill chain and leveraging dual-purpose improved conventional munitions (DPICM) and thermobaric munitions (Fox, 2017). Currently, Russia holds a range advantage over the United States for self-propelled and towed artillery systems (Gordon, 2015). Logistically, the Marine Corps cannot operate self-propelled artillery systems comparable to those of the Russia and the U.S. Army.

The M777A2 155mm towed howitzer is the sole towed artillery system in the Marine Corps arsenal. The M777A2 fulfills an expeditionary niche for the Marine Corps but lacks the maneuverability, range, and protection offered by self-propelled systems. The Marine Corps has extended the range of the M777A2 through base-bleed and rocket assisted projectiles (Gordon, 2015) that can provide some limited increased survivability by enabling longer range counterfire engagements. However, without the funding for a new artillery system and the limited availability of extended range munitions, the Marine Corps needs to consider other methods to increase artillery effectiveness.

The M777A2 is the most technologically advanced towed howitzer to date. The M777A2's Digital Fire Control System (DFCS) allows the weapon to communicate digitally with the fire support command and control system Advanced Field Artillery Tactical Data System (AFATDS). Marine Corps doctrine does not fully utilize the capabilities of the DFCS. Traditional artillery employment at the battery level involves the employment of howitzers within a battery or platoon structure. Communication, control, and logistical limitations dictates standard operating procedures found in doctrine and are discussed further in the literature review. With the implementation of the DFCS, previous limitations are irrelevant. The DFCS's capabilities present the U.S. Marine Corps with a separate option to increase survivability; distributed operations (DO). Distributed operations for an artillery battery involve dispersing a battery's howitzers over a spread of gun positions instead of in one or two positions traditionally done within a battery or platoon structure. This research assesses new M777A2 employment options within current force structure and to increase the chance of survival for U.S Marine Corps artillery units.

Map Aware Non-Uniform Automata (MANA) is an agent-based simulation tool developed by the New Zealand Defense Technology Agency (Moffat, 2006). MANA allows users to design a combat scenario to assess a change in doctrine or weapon system. In this case, MANA allows the researcher to evaluate differences in force structure or force employment options in a simulated combat environment. Conveniently formatted outputs capture the results of the simulation. The simulation allows the user to define the agent characteristics to include interactions with the environment and the opposing force (Moffat, 2006). In this case, MANA provides a platform to explore if U.S. Marine Corps artillery can effectively fight and survive against a near-peer adversary.

B. BACKGROUND

1. Russian Artillery

The Russian military organizes its forces to maximize its tactical goals. The brigade is the standard operational structure for Russian forces (Grau & Bartles, 2016). The artillery forces within a brigade consist of several types of tubed, missile, and rocket artillery. For this thesis, the focus is self-propelled, towed, and Multiple Launch Rocket System (MLRS) platforms. A brigade contains two self-propelled artillery battalions and one MLRS battalion. Each self-propelled battalion has eighteen howitzers separated into three batteries of six 2S19 MSTA-5 platforms or six 2S1 Gvozdika platforms per battery (Grau & Bartles, 2016). The MLRS battalion has eighteen MLRS launchers made up of three batteries with six BM-21 122mm MLRS launchers per battery (Grau & Bartles, 2016). The Russians organize units within the brigade depending on the operation. Artillery forces commonly attach to ground units to form brigade tactical groups (BTG) depending on the operational scenario.

The BTG task organizes ground forces with artillery forces to create a combined arms force. Russian military strategy emphasizes the firepower brought by the artillery force so much so that "the Russian army is artillery centric" (Grau & Bartles, 2016). As with U.S. Army and U.S. Marine Corps doctrine, the Russian military heavily employs fire and maneuver throughout their tactics with the mindset that artillery conquers and infantry occupies. As a result, modernizing the artillery force is a top priority for the Russian Army (Grau & Bartles, 2016).

There are two lines of effort for the modernization of Russian artillery. The first is to develop new self-propelled systems with automated turrets to increase firing rates (Grau & Bartles, 2016). The end state is an automated turret system transferrable to other platforms outside the artillery community. The second Russian effort is to refurbish existing systems instead of retiring them. This effort includes upgrading digital fire control systems to increase the firing rate and decrease the duration of the fire support process by removing redundancies. Russian modernization drives changes to doctrinal practices such as integrating unmanned aerial systems (UAS) into the fire support chain.

In its latest conflict, Russia showcased the modernization of its artillery force in Ukraine. On July 11, 2014, Russian artillery destroyed two battalion's worth of Ukrainian mechanized equipment (Fox, 2017). The Russians employed a BTG in Eastern Ukraine outfitted with strong artillery forces and UAS. The attack utilized UAS to locate and identify Ukrainian forces through digital emissions. The UAS transmitted targeting data to the BTG to execute an artillery barrage. Upon the completion of the barrage, the UAS returned to conduct battle damage assessment (BDA). This single attack sent shockwaves through the international military community and specifically the U.S. Army and Marine Corps due to sheer efficiency of the kill chain in terms of speed and accuracy.

2. United States Marine Corps Artillery

The force structure and equipment set of the U.S. Marine Corps is driven by an expeditionary mindset. The expeditionary mindset is defined within the U.S. Marine Corps as “a fundamentally expeditionary organization designed and intended to project military force overseas” (United States Marine Corps [USMC], p. 44, 1998). The U.S. Marine Corps facilities the projection of military force overseas through its ties with the U.S. Navy. As a result, the U.S. Marine Corps force structure is influenced by the support limitations of the U.S. Navy. A partnership with the U.S. Navy requires the U.S. Marine Corps to transport equipment and personnel on ship then move that equipment and personnel from ship to shore. The U.S. Navy is limited in its ability to facilitate the movement of equipment and personnel from ship to shore.

The U.S. Marine Corps’ tip of the spear mentality and the U.S Navy’s limitations of support restrict the type of equipment the U.S. Marine Corps utilizes. For example, compared the U.S. Army, the U.S. Marine Corps has significantly fewer tanks. Tanks are difficult to transport and require extensive logistical support. Due to those considerations, the U.S. Marine Corps limits the number of tanks or tank like-systems in its inventory. This is the reason the U.S. Marine Corps does not possess any self-propelled artillery platforms like the U.S. Army. The 109A2 Paladin is a self-propelled artillery platform that combines a tracked vehicle with an artillery tube. The Paladin, comparable to a tank in size and weight, presents the same logistical considerations.

The Marine Corps organizes its artillery units to support the Marine Air Ground Task Force (MAGTF) concept. Within the Marine Corps, there are four artillery regiments, three active duty and one reserve. The regimental composition is not uniform across divisions. For example, the 10th Marine Regiment is comprised of two battalions while the 11th Marine Regiment has four battalions. The current organization is the result of force reduction and budget constraints. For simplicity, the paper assumes a uniform structure of artillery regiments. A regiment has three battalions. Each battalion has three firing batteries with six towed howitzers per battery. An artillery regiment supports a division while an artillery battalion supports an infantry regiment and a firing battery supports an infantry battalion. The size of the supporting artillery force is dependent on the operational deployment of the supported unit. The M777A2 is the primary weapon system of Marine Corps artillery firing batteries.

The M777 lightweight 155mm towed howitzer entered service in 2003. The M777 replaced the M198, the workhorse of the artillery community for over 20 years, and capitalized on its deficiencies (Gourley, 2014). The M777 platform combined emerging technology with the optical fire control. The M777 upgraded to the M777A1 with the implementation of the DFCS. The DFCS upgrade included a Defense Advanced GPS Receiver (DAGR), Chief of Section Display (CSD), and Gunner and Assistant Gunner Displays (Goldman, 2007). The Communication-Location Assembly (CLA) is a communications suite added to the howitzer. The CLA contains a radio, amplifier, antenna, and DAGR. The radio allows the section chief to use the CSD to pass howitzer information to the Fire Direction Center (FDC) through AFATDS. With a software upgrade in 2007, the M777A1 became the M777A2 (Goldman, 2007). The M777A2 software upgrade made the howitzer precision-guided munition capable with the Excalibur munition (Goldman, 2007). Artillery doctrine did not adapt to the introduction of the DFCS.

C. PURPOSE

This study uses MANA to assess the impact of employment options on U.S. Marine Corps artillery unit survivability against a near-peer adversary. To provide a recommendation about the effectiveness and survivability of distributed operations for artillery units, this study develops two scenarios by applying U.S. Marine Corps and Russian artillery doctrine to define the characteristics of the Blue and Red force. For the Blue force, one scenario models a battery employment and the other models a distributed employment. The U.S. Marine Corps currently uses two employment options, battery and platoon. To limit the scope of the study and the size of the experiment, this study focuses on only two employment options. Battery employment is the most common employment option and the distributed is the most controversial. The study answers the following questions:

- Which employment methods from the two tested increase survivability against a near-peer adversary?
- Which movement and tactical considerations have the most significant impact on survivability within the two employment methods?

D. METHODOLOGY

This study uses MANA to answer the research questions. Two combat scenarios focus on artillery battery's engaging in a counter battery fight. The difference between the two scenarios lies in the employment method of the U.S. Marine Corps artillery unit, whether distributed or employed as a battery. The study uses current weapon systems and doctrine to develop and define properties in the scenario. The simulation ends with the destruction of either Red or Blue's artillery unit. At the conclusion of the simulation, MANA analyses the scenarios with pre-determined measures of effectiveness and variables of interest.

Data is collected from the experiment. The experiment runs 6,450 simulations for each scenario. The experiment is defined using five variables of interest from the experimental design. Follow on chapters discuss in detail the experiment and all variables. Data is collected from the experiment and analyzed with survivability as the measure of effectiveness. Survivability is defined as the ability to provide fire support and minimize friendly casualties. The analysis uses defined variables to measure survivability. Results from the analysis drive the conclusions and recommendations about employment methods in the Marine artillery community.

E. ORGANIZATION

Chapter II presents a literature review of distributed operations and the discussion of survivability in the artillery community. Academic, military, and professional artillery publication sources identify and discuss doctrine and weapon systems. The review compares artillery systems to identify the capability gaps that support the Marine Corps' priority for survivability. Artillery doctrine is discussed to identify the absence of the DFCS in current tactics.

Chapter III describes the methodology for the study. It also describes the operational scenario used for the simulation. The chapter provides an in-depth discussion of the scenarios such as the characteristics of the opposing forces and the simulation environment. The chapter discusses how MANA is a sufficient platform to explore the research question. Additionally, the chapter covers the characteristics of MANA, the assumptions used in the model, and the limitations of the model.

Chapter IV presents the experimental design of the model. This chapter includes the variables of interest and the method for running the experiment.

Chapter V presents the findings and results of the thesis. The analysis section dissects the casualty results of the model, as seen through the impact on survivability.

Chapter VI provides a summary and recommendations for employment methods based on the outputs of the model as well as recommendations for future work.

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II. LITERATURE REVIEW

Adopting emerging technology into artillery tactics is not a widely discussed field. The specificity of the research questions limits the discussion to Naval Postgraduate School studies, think-tank research projects, military doctrine, and professional military magazine publications. Studies funded by the U.S. Congress led to the identification of capability gaps in the United States' artillery equipment. Professional military officers offer their insights in various professional publications such as *Fires* and the *Marine Corps Gazette*. Students at the Naval Postgraduate School explore hypotheses through modeling, simulation, and other academic studies. The purpose of this literature review is to discuss works that address methods for increasing the survivability of artillery units against near-peer adversaries and the state of distributed operations in the U.S. Marine Corps.

To increase survivability and effectiveness, the U.S. Marine Corps places value on the maneuverability of the M777A2. The Marine Corps defines artillery maneuverability as the ability to externally transport the howitzer between locations. In this context, maneuverability and transportability are used interchangeably. Considered a genuinely expeditionary fire support platform, the M777A2 is an externally transportable platform due to its lightweight and niche fitting aspect in amphibious warfare (Crane, 1999). The Marine Corps considers these factors vital to the platform's survivability against other artillery forces. However, the platform falls short in many categories when compared to its foreign counterparts. A 2015 RAND research report titled "Comparing U.S. Army Systems with Foreign Counterparts" identified critical capability gaps of the U.S. Army and U.S. Marine Corps artillery systems when compared to foreign counterparts. The report found the U.S. Army's M109A6 Paladin range and rate of fire inadequate compared to foreign systems in use. In respect to towed artillery, the report concluded that M777A2 emplacement and displacement times are inadequate and lacks the armor protection like that of self-propelled systems but compensates as a lightweight, affordable platform that fires a variety of effective rounds (RAND, 2015). To gain and maintain an advantage in a conventional fight, RAND recommends the U.S. military continue to expand long-range precision fires.

After Russia's recent display of artillery firepower in Ukraine, calls for the replacement of the M777A2 became louder and more frequent. Several U.S. military officers question the advertised advantages of the M777A2: lightweight and transportable. When externally transported, the M777A2 is left without the vehicle required to tow it, or prime move, and, therefore, unable to move around the battlefield (Kane, 2017). Replacement advocates champion either self-propelled systems like the Caesar and Hawkeye or favor an even lighter system like the M119A2 (Browne, 2018). The arguments have one thing in common: a belief that a replacement to the M777A2 must be able to fight and survive against a near-peer threat. Supporters of self-propelled platforms argue that the system's ability to execute a fire mission and displace quickly help make it harder to target with counterbattery fire, whereas, the displacement for a towed system involves more steps and personnel, resulting in a slower displacement time. Any self-propelled option would need to fit within the expeditionary mindset of the U.S. Marine Corps.

One such example of an expeditionary self-propelled system is provided by a 2018 study at the Naval Postgraduate School. This study identified the Hawkeye 105mm self-propelled howitzer as a replacement to the M777A2 (Browne, 2018). Using a capability-based assessment, the author compared multiple towed and self-propelled artillery platforms with several performance metrics. Most notable for the Marine Corps, the author emphasized the importance of range, which he based on the capability gap identified between the U.S. and foreign systems (Browne, 2018). The study found that although the Hawkeye's range was less than that of the M777A2, the Hawkeye compensated for it in transportability and mobility (Browne, 2018). The ability to fit more Hawkeye systems on Landing Craft Utilities (LCU), Landing Craft Air Cushions (LCAC), and CH-53s increased its transportability. Unlike the M777A2, the Hawkeye is a 105mm howitzer mounted on a High Mobility Multi-Wheeled Vehicle (HMMWV) making it more mobile than the M777A2, specifically after a helicopter insertion.

The acquisition of a new artillery system is a viable long-term solution to increasing artillery survivability on the battlefield. However, in today's fiscally constrained environment and the reality of a lengthy and complicated acquisition system, changing Tactics, techniques, and procedures (TTPs) must be used as a short-term solution. In a 2017

Naval Postgraduate school thesis, the author used stochastic models to find the optimal time for an artillery battery to move after firing (Shim, 2017). The study found a balance between survivability and delivering adequate fire support. The author concluded effective fire support relied on a unit's ability to mass fires, in which a moving unit is incapable of executing fire missions (Shim, 2017). The artillery unit must avoid moving after firing one volley, and the optimal time to stay in one position to increase survivability was 10 to 15 minutes (Shim, 2017). It is worth noting that the study examines Korean self-propelled artillery without varying the employment methods of the artillery units. However, this study gives a view into reducing the risk of an artillery unit where counter-battery radars are present, and all units are within the range fan of the other's artillery. It is worthwhile to study how the M777A2's specific digital capabilities impact survivability in comparison to studies such as this one. Specific to Russian artillery in Ukraine, a 2017 article in Fires states that towed artillery has its vulnerabilities on the battlefield, but "there is still hope to revive the platform if leaders at the battery level train creative TTP's" (Kane, 2017, p.29). As discussed earlier, the current doctrine used by Marine artillery units does not reflect the M777A2's DFCS capabilities, but units can train to them.

In 2005, then Commandant of the Marine Corps, General Michael Hagee authored A Concept for Distributed Operations, to define and discuss distributed operations for the Marine Corps. General Hagee described the concept as "the deliberate use of separation, coordinated, interdependent, tactical actions enabled by increased access to functional support, as well as by enhanced combat capabilities at the small-unit level" (Hagee, 2005, p. i). General Hagee's concept fueled further discussion and analysis of the feasibility of distributed operations.

In 2006 the Naval Research Advisory Committee (NRAC) published a report on distributed operations for infantry units. The study took place over five months from February to June 2006 through a partnership with Marine Corps Combat Development Command (MCCDC) and Marine Corps Warfighting Lab (MCWL). The purpose of the study was to explore how distributed operations would impact future technology and training. The report found that as units separate across the battlefield, the situational awareness of small unit leaders, radio communications, and casualty care become major issues (NRAC, 2006). Increased separation strained infantry units and their existing capabilities at the battalion and small unit level in three specific areas: communications, logistics, and education and training (NRAC, 2006). A common theme emerged from each area; Marines needed more equipment and more training.

A switch from conventional to distributed operations can see the separation of platoons in a company increase from 1 kilometer to 20 kilometers in a rural environment and 1 to 3 city blocks in an urban environment (NRAC, 2006). To communicate effectively, the committee identified the need for "new communications equipment, architecture, and doctrine to address basic connectivity as well as the proliferation of nodes on the battlefield" leading to the identification of equipment, personnel, and proficiency shortfalls within the current force structure (NRAC, 2006). The increase in complexity for the communication network is due to the necessity of units to stay in contact with higher, subordinate, and supporting units, specifically fire support, as shown in Figure 1. In terms of logistics, distributed operations shifted the point of delivery distribution logistical burden from the company to the platoon and squad level, also identifying critical shortfalls in resupply tactics and small unit leader proficiency and training. The necessity for additional training must be balanced with the operational availability of small unit leaders as time spent in training courses takes a Marine away from their unit for a period.

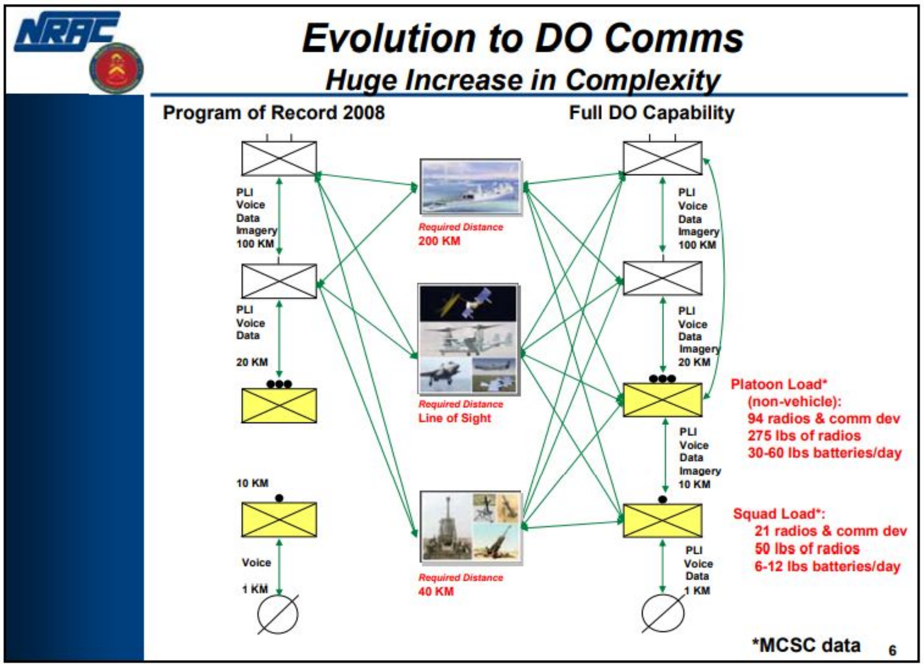

Figure 1. Distributed Operation Communication Diagram.
Source: NRAC (2006).

The shortfalls hold when modeled in simulations. A 2005 study done by a Naval Postgraduate student evaluated the effectiveness of distributed operations for the Marine Expeditionary Rifle Squad (MERS) in urban operations using MANA. Urban operations are comparable to distributed operations because of the requirement to operate individually and separate from other units (Sanders, 2005). The author treated a Marine Rifle squad as a system to evaluate its performance as a single unit. The study concluded that the two main measures of effectiveness (MOE) are survivability and lethality (Sanders, 2005). Essentially, the probability of mission success is dependent on the training and lethality of the MERS (Sanders, 2005). The findings of the study highlight the necessity for advanced training for small unit leaders, which is central to the training and education of the individual Marine discussed in the 2019 Commandant's Planning Guidance (CPG).

However, it is not accurate to carry over the results from a distributed infantry unit to an artillery unit. No such study of a distributed artillery unit exists, but examining the organization, and employment tactics of High Mobility Artillery Rocket System (HIMARS) is useful to this study. Currently, HIMARS units operate in a distributed fashion. A 2006 article in the Marine Corps Gazette adapted from the artillery publication Fires, discussed the proof of concept done for the Marine Corp's HIMARS. An exercise conducted by 5th Battalion, 11th Marines, found "the ability to operate HIMARS as 3 x 2 was found to be operationally sound" (Russo, 2006). Operating in this fashion is due to HIMARS unit's ability to conduct long-range communications, logistics resupply, and strategic lift (Russo, 2006).

In contrast to its infantry counterpart, HIMARS' possesses organic communications assets and the personnel to operate such equipment. HIMARS launchers use AFATDS to conduct digital communications and for the transmission of firing data. The M777A2 uses the CSD and the DFCS the way a HIMARS uses AFATDS. The DFCS is the primary means of communicating with the AFATDS controlled by the battery FDC. If the DFCS of a howitzer is within range of the battery FDC AFATDS, it can process digital fire missions. As the DFCS continues to receive technological upgrades to its global positioning and communications systems, the HIMARS employment method becomes increasingly viable for M777A2 units.

Marine Corps artillery publications address survivability through operational employment. Dispersed formations increase survivability from IDF attacks. When position limitations hinder the ability to disperse a battery, platoon operations offer an alternative. The foremost reference on artillery tactics, *Tactics, Techniques, and Procedures for the Field Artillery Cannon Battery*, states that platoon operations enhance flexibility and survivability for an artillery battery (USMC, 2016b). However, operating as a platoon sacrifices the command and control and local security firepower offered by a battery position in exchange for flexibility through a smaller unit size. Platoons utilize smaller gun positions that offer more cover and concealment for the howitzer sections. Platoon operations reflect the smallest operational employment size due to the method of lay and personnel requirements.

The methods covered in Tactics, Techniques, and Procedures for the Field Artillery Cannon Battery are heavily rooted in manual methods for employment and emplacement. Traditionally, manual methods restricted employment methods to battery or platoon emplacements. The selection of firing positions depended on the ability to conduct manual methods of lay for the howitzers. The emplacement of a howitzer uses an aiming circle to transfer location data to the howitzer from a survey control point. This method correctly orients the howitzer on the azimuth of fire for the target area. This method also requires numerous personnel to operate the aiming circles and verify howitzer positions as well as line of sight with at least one howitzer. Safety guidelines required the personnel to be a certain rank and safety certified. Personnel requirements and the manual methods of lay have limited a battery to battery emplacements with all six guns in the same position or platoon emplacements with three guns in two positions. The M777A2's DFCS negates those emplacement restrictions.

The DFCS allows the M777A2 to emplace in a gun position digitally. First, the howitzer initializes at a survey control point to synchronize the DFCS with the DAGR for location accuracy. The section chief inputs the gun position grid and the azimuth of fire to the target area. The DFCS allows the section chief to use the outputs on the CSD to orient the howitzer and report its position to the FDC with a ten-digit grid coordinate. The DFCS method of lay is faster and more accurate than the optical fire control method (USMC, 2011). A DFCS emplacement is faster, requires less gear, and requires fewer personnel. Unlike manual employment, battery personnel is only required to verify the howitzer's position for safety purposes. The DFCS method of lay decreases the required safety certified staff to lay a howitzer section down to one. The ability to self-locate and emplace with less safety personnel negates the necessity for an artillery battery to employ as only a battery or platoon. DFCS opens the door for a new method of survivability for all artillery units equipped with the technology.

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III. MODEL DEVELOPMENT

A. INTRODUCTION

This chapter discusses the scenarios used in the simulation. The scenarios represent modified operations orders from current field exercises conducted by Marine Corps artillery units in the Fleet Marine Force (FMF). In addition to the scenario background, force organization, and tactics, this chapter discusses the MANA simulation tool itself. Most importantly, this chapter finishes with a detailed discussion on the data and assumptions used in the model.

B. SCENARIO DESCRIPTION

1. Overview

The purpose of this simulation is to model a scenario that pits two near-peer artillery competitors against each other to measure the survivability of different employment options. To do so, the researcher develops two scenarios to vary the Blue artillery employment between battery employment and distributed employment. Force size is limited to emphasize simplicity and allow for multiple iterations of the simulation to gather enough trials required for the study. For example, neither side will use armored vehicles since the focus of this study is to use various measures of effectiveness to observe the interaction between artillery agents. The infantry agents serve as targets and target identifiers for both sides' artillery forces. Accurately modeling doctrinal tactics for the artillery agents is the emphasis of the scenario.

2. Battery Employment Scenario

A Battalion Tactical Group of the Red force is advancing on the city of Kyiv from the east. Blue, a battalion-size force, is tasked with establishing a hasty defense in the unit's area of operations (AO) to disrupt the Red advance. The AO, west of Kyiv, consists of sparsely populated farmland trafficable by major highways and improved roads. As Red advances from the east toward Kyiv, Blue establishes a defense in a heavily wooded area just outside of the city.

a. Enemy (Red)

The Red force models a conventional near-peer adversary to the United States. The Red force is simplified to reduce the total number of agents in the simulation. Red includes three infantry companies, one self-propelled artillery battery with six Msta-S 2S19s, a headquarters element, and one 1L219M "Zoopark-1M" counter-battery radar vehicle. The infantry companies are not mechanized to reduce the complexity of the scenario.

Additionally, the infantry is restricted to small arms, specifically the AK-47 automatic rifle and PKM light machine gun (LMG). Each infantry company is treated as a squad in MANA with similar characteristics. The artillery battery acts as one squad with a set of similar characteristics.

The scenario begins after the BTG transitions from a tactical march to a combat formation upon contact with the enemy. The combat formation consists of two echelons with the first echelon composed of the three infantry companies in line and the supporting artillery battery to the rear of the formation in the second echelon (Grau & Bartles, 2016). The second echelon is located 1.5 to 2 kilometers behind the first echelon (Grau & Bartles, 2016).

b. Friendly (Blue)

The Blue force is modeled after a reinforced United States Marine Corps infantry battalion. The force is simplified to reduce the total number of agents in the simulation. Blue contains three infantry companies, one recon team operating as forward observers, one artillery battery with six M777A2 lightweight towed howitzers, one FDC, and one AN/TPS-80 ground/air task-oriented radar (G/ATOR) in support. Infantry companies establish a hasty defense equipped with M4 carbines and M240B LMGs. The defense occupies a position east of Kyiv with the artillery battery and G/ATOR located inside the wooded area.

Under the battery employment scenario, the artillery battery operates as a single unit. Terrain dictates gun positions and the dispersion between howitzers. As defined, the artillery battery shoots and moves as a single unit. When the battery displaces, the unit's fire capability (FIRECAP) updates to zero and is therefore unable to provide fire support until emplaced in its subsequent gun position. Gun positions are pre-selected to decrease the time the unit is not firing. The size and orientation of the gun position dictates the dispersion between howitzers. Optimal dispersion between howitzers is between 50 to 200 meters within a single gun position. Figure 2 depicts one example of a battery position.

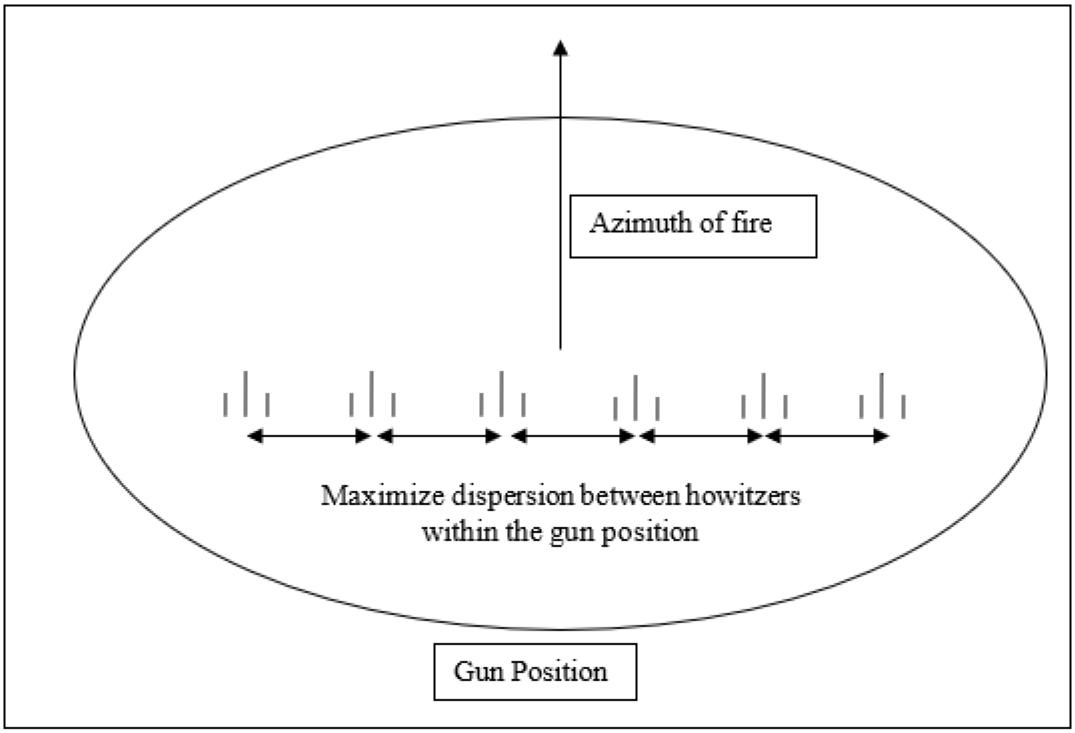


Figure 2. Example Diagram of a Gun Position Layout with Battery Employment

3. Distributed Employment Scenario

a. Enemy (Red)

No change to the Red force composition and mission.

b. Friendly (Blue)

No change to the infantry Blue force composition and mission. Blue artillery operates as independent howitzers sections. Howitzer sections disperse throughout the wooded area anywhere between one and eight kilometers from the FDC and the other sections. Figure 3 provides an example of the dispersion of distributed howitzers. A wider selection of gun positions is available to the howitzer sections because of the section's smaller footprint. Howitzer sections utilize the tree line for cover and concealment from enemy observation and artillery fire. Individual howitzer sections move independently from the other sections. The FDC controls all six sections but gives each section the flexibility to control its individual displacement within the FDC guidance. Section independence allows for the battery to maintain a FIRECAP while sections move.

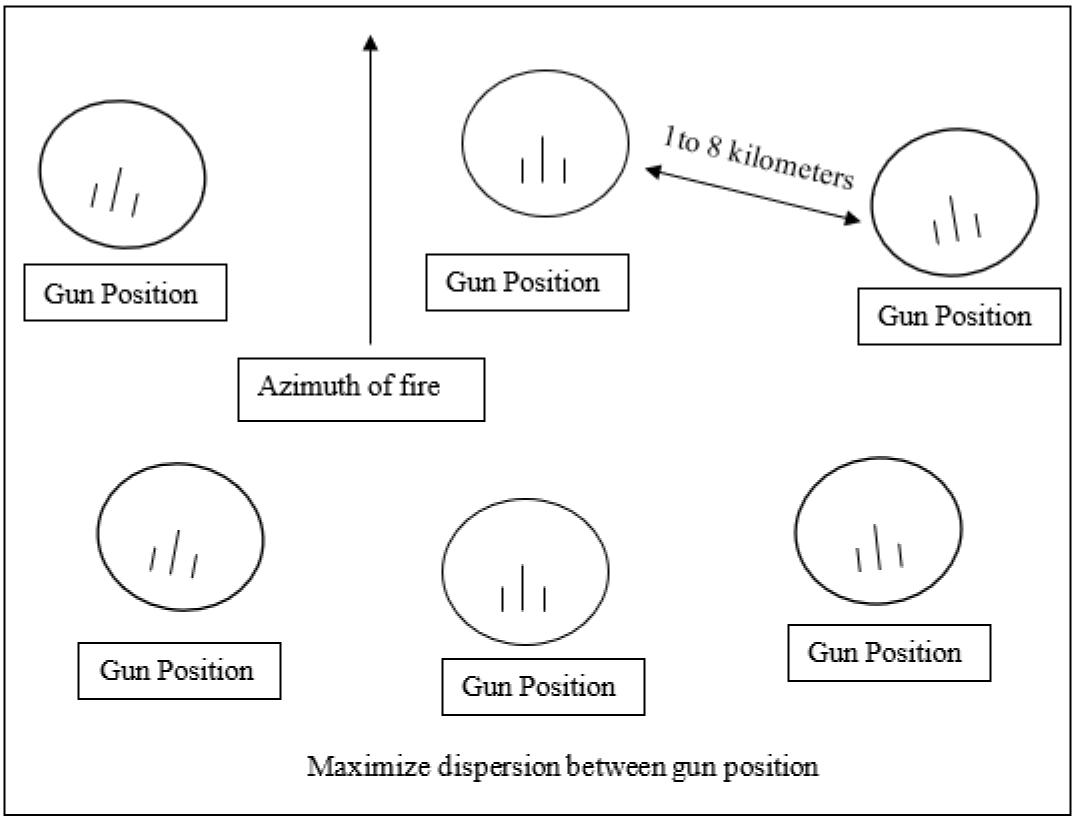


Figure 3. Example Diagram of a Distributed Battery

C. CHARACTERISTICS OF THE MANA MODEL

MANA is an agent-based model developed by the New Zealand Defence Technology Agency (DTA) (McIntosh et al., 2007). The researcher chose MANA because the program allows the designer to define how agents make decisions through interactions with each other and the terrain. As a stochastic model, the interactions between agents are fluid as behaviors change with the information taken in from the environment and other agents.

MANA defines agents as squads. The user defines the squad's characteristics such as allegiance, composition, and movement speed through several properties' tabs. One of the most useful tools in MANA is the ability to define the squad's behavior through trigger states. Trigger states define how agents act in certain scenarios using personality weightings. This concept allows the researcher to define distinct personalities for Blue artillery units as a method to differentiate behaviors in the distributed scenario from the battery scenario. Trigger states allow the researcher to define how the artillery units act in different states specifically. For example, without the threat of counter-battery, artillery provides fire support for the infantry agents. Once identified and targeted by enemy artillery agents, firing rate, movement criteria, and targeting preferences change. MANA's ability to act as a low-resolution, plug, and play simulation tool makes it a suitable tool for this thesis' problem set.

1. Goal

The goal of the MANA simulation is to evaluate the survivability of Blue artillery forces in different employment options. Blue artillery's survivability depends on dispersion and avoiding enemy counter-battery fire. The Red force behaviors and weapon capabilities remain the same for both scenarios. When analyzed, defined outputs show how the performance of the Blue artillery force changes as the behaviors change with employment.

The presence of counter-battery radar and enemy artillery agents force a balance between fire support and avoiding enemy artillery fire. The scenario forces artillery units to process fire missions in support of the infantry agents while remaining mindful of the enemy artillery threat. Once engaged by counterbattery, artillery agents interact with the terrain to find cover and new gun positions. The separate employment options dictate how, when, and where the Blue force artillery displaces.

2. Conceptual Model

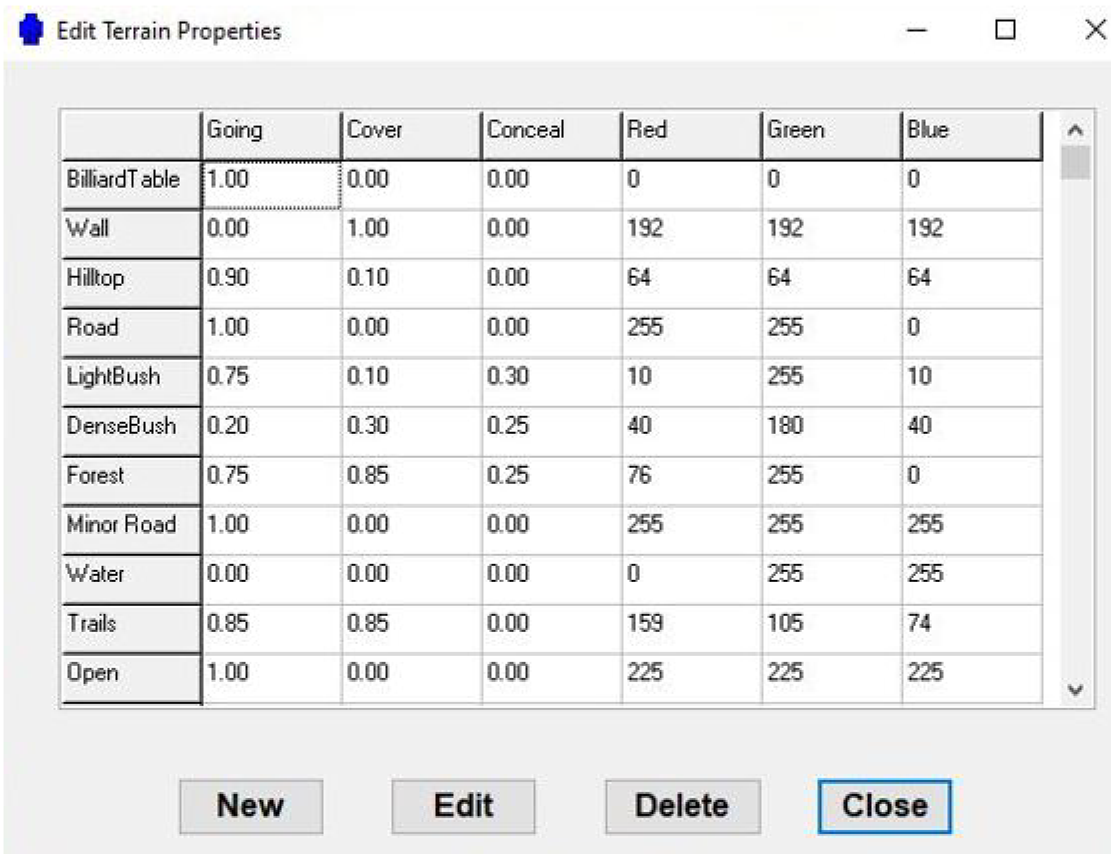
The model focuses on the interaction between opposing artillery units. The researcher strips the forces of units not pertinent to the situation, such as tanks and troop carriers. These units are not important to the interaction between the artillery units. The focus is to measure the effects of artillery units engaging each other and not artillery survivability against infantry or armored units. Additionally, the scenario limits the number of infantry agents to increase the speed of the model. Red attempts to penetrate Blue’s defense with infantry and IDF to support. Blue attempts to destroy Red infantry and artillery with its IDF assets. Infantry units identify targets to force artillery agents to execute fire missions and trigger the opposing side’s counter-battery capability and procedures. The side which eliminates the opposing artillery unit wins the battle.

3. Terrain and Scale

The model represents an area east of Kyiv. Battlefield dimensions are 30 kilometers along the north-south axis and 50 kilometers on the east-west axis. Battlefield terrain consists of flat-open farmland with several suburban centers and scatted pockets of wooded areas. One large wooded area runs north to south on the western side of the map. Except for wooded areas and large creeks, the terrain is trafficable by foot, wheeled, and track vehicles. Several highways and improved roads run throughout the battlefield.

Figure 4. Terrain Map

A Windows bitmap terrain map created by the researcher represents the actual terrain. Colors represent various types of terrain. Figure 4 depicts the terrain map used in MANA to represent the scenario location. Terrain impact is defined and represented through terrain properties. Terrain properties impact agents in three categories: Going (movement speed), Cover (hit rate), and Concealment (sensor detection) (McIntosh et al., 2007). Possible values range from 0.00 to 1.00. For movement speed, terrain with a value of 0.00 is impassable to agents. Terrain with a value of 1.00 does not block or slow the agent's movement. A value of 0.00 for cover represents terrain that does not provide any protection from enemy fire, while a value of 1.00 blocks all enemy fire. A 0.00 value for concealment represents terrain that does not block enemy sensors while a value of 1.00 represents terrain impenetrable to sensors. Figure 5 shows the MANA terrain properties used for the scenario.



	Going	Cover	Conceal	Red	Green	Blue
BilliardTable	1.00	0.00	0.00	0	0	0
Wall	0.00	1.00	0.00	192	192	192
Hilltop	0.90	0.10	0.00	64	64	64
Road	1.00	0.00	0.00	255	255	0
LightBush	0.75	0.10	0.30	10	255	10
DenseBush	0.20	0.30	0.25	40	180	40
Forest	0.75	0.85	0.25	76	255	0
Minor Road	1.00	0.00	0.00	255	255	255
Water	0.00	0.00	0.00	0	255	255
Trails	0.85	0.85	0.00	159	105	74
Open	1.00	0.00	0.00	225	225	225

Figure 5. Terrain Properties

The time scale represents one step as one second. 100,000 is the maximum number of time steps for a MANA scenario. A one second time step allows for a maximum of 1,667 hours of simulation if needed. The set time scale allows for granularity in the data without slowing down the simulation unnecessarily. The maximum number of time steps for the simulation is 75,000. This value is discussed further in the experimental design section of Chapter IV.

4. Red Force

Red contains six squads: three infantry squads to represent three companies, a squad of artillery, a headquarters squad, and a squad of counter-battery radar. The infantry squads are reduced from the usual company size of 101 to 10 to reduce the unnecessary number of agents in the simulation. In total, Red has 30 infantry agents, one radar agent, six artillery agents, and one headquarters agent.

At the start of the scenario, Red completes its transition from a tactical march to a combat formation. Red is unaware of Blue's position, and the Blue infantry agents and forward observer identify Red positions. After contact, Red infantry finds cover and locates the Blue force. The model programs infantry agents to flank and attempt a penetration until the force reaches a standoff distance.

Red's equipment is defined using *The Russian Way of War*. Infantry agents organic weapon systems such as the AK-74 and PKM LMG. Artillery agents utilize the 2S19-Msta-S self-propelled 152mm howitzers. The author chose the weapon systems due to their extensive use in the Russian military and similar characteristics to the Blue force weapon systems. Red infantry agents go through two separate state changes while the artillery agents transition through several, as shown in Figure 6. Transition times between states comes from the subject matter expert advice and the researcher's interpretation of Russian military doctrine.

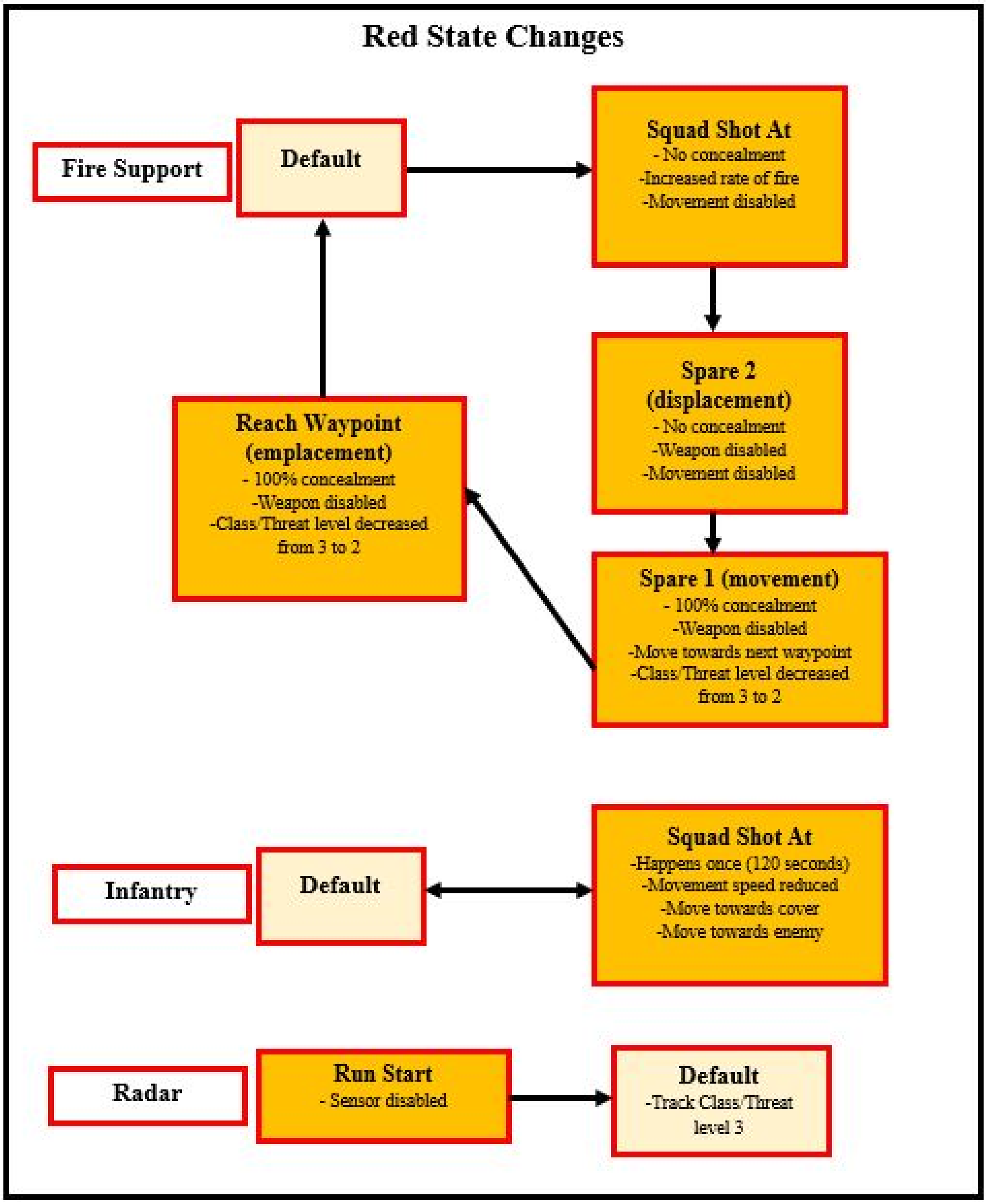


Figure 6. Red State Changes

5. Blue Force

The Blue force contains seven total squads in the battery scenario and twelve total squads in the distributed scenario. In the battery scenario the Blue howitzer squad contains all six guns. In the distributed scenario, each howitzer represents a squad. The five additional Blue squads account for the five-squad difference between the scenarios. The forward observer team has maximum concealment and armor thickness. The forward observer team represents the intelligence advantage of a force in an established defense. The forward observer is the main target identifier for the Blue artillery force and is used to minimize the number of communication links on the battlefield and is, therefore, kept hidden from the Red force. Blue infantry agents occupy a defensive perimeter. Blue artillery agents have several pre-identified gun positions located inside the wooded area in the western portion of the battlefield. Blue's distributed howitzers behave differently than the howitzer's operating as a battery. The differences in behavior come from subject matter advice and the author's interpretation of Marine Corps doctrine. A smaller footprint allows distributed howitzers displace faster than howitzers in the battery scenario. One emplaced howitzer maintains units FIRECAP, so sections moving simultaneously allows Blue to maintain IDF support while being harder to target.

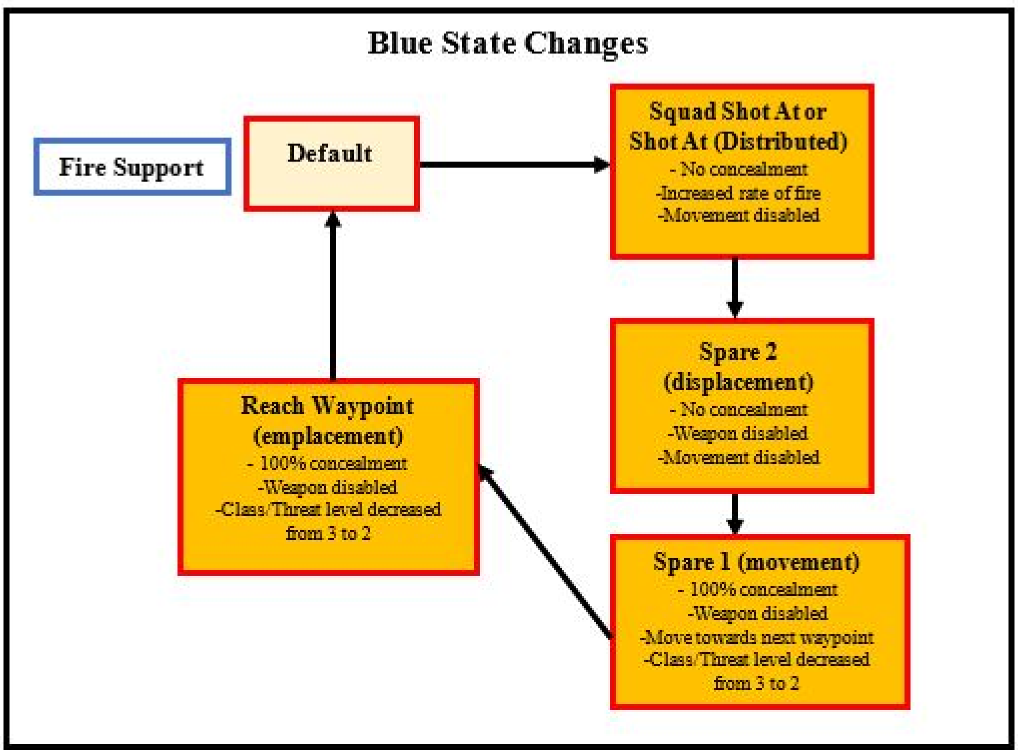


Figure 7. Blue State Changes

6. Logistical Support

The scenario does not incorporate logistics.

7. Data Sources

Overall, the data used as inputs for the combat scenarios come from the researcher's personal experience, subject matter expert advice, military doctrine, and open-source data such as the Federation of American Scientists (FAS) and Jane's by HIS Markit. The researcher referenced previous studies to decide on what sources to use in the absence of classified information. A previous study done at the Naval Postgraduate School concluded that the input values provided by modeling and simulation organizations such as the Defense Modeling and Simulation Office (DMSO) and Army Material Systems Analysis Activity (AMSAA) are too complex and not worthwhile for a low-resolution system such as MANA (Michel, 2006). Instead of data from those organizations, the researcher cross-referenced open source information with doctrine and subject matter experts to keep data consistent. Parameters are tailored to the capabilities and limitations of MANA to maintain consistency throughout the scenario.

8. Assumptions

To develop the scenario within the limitations of the time frame of this study and limitations of MANA, the study makes several key assumptions. Those assumptions are follow.

1. The 2S19-Msta-S used for the Red force because of its wide-spread use and similarities to the M777A2 in range and ammunition.

2. Artillery agents use one type of projectile that produce similar effects.

3. The scenario scales the size to a battalion sized battlespace and unnecessary units like tanks and armored troop carriers are left out.

4. Blue always knows Red's location because of the advantage of being in the defense with reconnaissance teams forward.

5. Rocket artillery is not available.

6. Air support is not available.

7. Infantry agents require an increased amount of hits to kill to allow the smaller force to represent an actual infantry company. Hits to kill is also increased to keep infantry forces in the fight longer.

8. Radar ranges are increased so both sides can track the opposing IDF forces.

9. Communications between squads are perfect.

Some MANA limitations require workarounds to define desired agent behavior. The limitations and fixes follow.

IDF firing on the move. MANA allows IDF units to fire on the move.

- **Workaround.** IDF agents transition through trigger states to simulate moving. Weapons are disabled in states where IDF agents move. Additional trigger states represent emplacements and displacements where weapons are also disabled.

- **Trade-offs.** It is not a common practice for self-propelled units to fire on the move. Work-around allows the researcher to define artillery emplacements and displacements accurately.

Radar. Radar senses targets based on time steps, not actions. Radar in MANA does not identify agent locations based on projectile information like counter-battery radars. Therefore, the radars can locate artillery agents at any time.

- **Workaround.** Radar sensors are disabled at the start of the scenario for 120 seconds. During the first 120 seconds, artillery agents fire on opposing infantry units. Disabling the radar sensors represents the actuality that counter-battery radars do not know enemy artillery locations before firing. The radar in MANA is set to only tracks artillery agents in the act of firing. During movement, the location of artillery agents are concealed from radar. IDF agent’s concealment properties vary based on their current state. For example, units have a higher concealment percentage in the default state than in the shot at state. The model uses concealment to realistically model radar in the simulation.

- **Trade-offs.** Radar in MANA locates IDF agents faster and more frequently than counter-battery radar. However, using radar in the simulation helps model communication latency or transmission time of the counter-battery kill chain.

Terrain. Radar detection and classification are blocked when terrain concealment values are close to 1. Counter-battery radar locates units based on projectile flight information, which is not blocked by the type of terrain selected for the scenario.

- **Work-around**. Since infantry agents are not identifying IDF units, concealment values for the terrain are set at zero. Locating IDF agents is done through radar that represents counter-battery radar.

- **Trade-offs.** Concealment lost by the terrain does not affect the overall goal of the simulation. Radar detecting IDF agents is vital to the execution of the scenario.

D. SUMMARY

The researcher designed the MANA scenarios to accurately model a counter-battery fight between two artillery batteries. The scenario location represents a tactical scenario that allows an artillery battery to exploit the terrain with distributed operations. Similar weapon systems are used in both scenarios and between the two forces to decrease the chance of a disproportional advantage in favor of one side. Trigger states manipulate agent behavior to represent artillery behaviors in combat. Lastly, the study makes several assumptions to reduce the size and complexity of the scenarios to work within the limitations of MANA.

IV. EXPERIMENTAL DESIGN

A. INTRODUCTION

The researcher designed the simulation with the ability to data farm the results. The process of data farming works to "manipulate our simulation models prospectively to maximize insights" (Sanchez, 2018). The Design of Experiment (DoE) process allows the researcher to manipulate many factors to explore the simulation. This process happens with the help of the Simulation Experiments and Efficient Designs (SEED) Center for Data Farming at NPS.

To data farm, the researcher designs an experiment with defined variables of interest with minimum and maximum values to run multiple iterations of each scenario. Manipulating the variables allows the researcher to vary the results of the scenario to explore various factors that influence the outcome of the scenario. Refining the variables and the debugging process for a better analysis takes place over multiple experiments. High-performance computers at the SEED Center allow the experiment to run thousands of iterations in a timely fashion.

This chapter begins with a discussion on the variables of interest chosen for the experiment. The section identifies the variables and the reasoning for their inclusion. A follow-on discussion regarding the DoE and Nearly Orthogonal Latin Hypercubes (NOLH) concludes the chapter.

B. VARIABLES OF INTEREST

This section identifies the variables or factors used for the experiment. This experiment uses the viewpoint of the Blue force to define controllable and uncontrollable factors. Controllable variables or decision variables are factors controllable by the Blue artillery battery commander. The noise variables are inputs used by the Red artillery force. The noise variables are uncontrollable from the Blue force perspective and remain set during the experiment.

Artillery units operate within their capabilities and following doctrine and unit standard operating procedures (SOPs). As discussed in Chapter II, M777A2 critics focus on the howitzer's slow emplacement and displacement time as compared to self-propelled systems. The selected variables of interest correspond to the discussion in the literature review and with doctrine. Battery leadership can control the inputs for these variables through unit SOPs and training. Battery and section proficiency weigh heavily on the values of these variables in actual combat scenarios. Therefore, the experiment selected these variables due to their popularity amongst critics and controllable nature by leadership and training. Table 1 lists the variables of interest.

Table 1. Variables of Interest

Factor #	Factor Name	Description	Min Value	Max Value
1	M777A2 Emplacement	The time it takes for M777A2 to emplace in a new position	30 (seconds)	300 (seconds)
2	M777A2 Displacement	The time it takes for M777A2 to displace from its position	20 (seconds)	120 (seconds)
3	M777A2 Time In Position	The time M777A2 stays in its current gun position after being shot at	60 (seconds)	900 (seconds)
4	Hits to kill	The number of hits required to destroy a M777A2	1	5
5	Rate of fire	The number of rounds per minute during the Shot At or Squad shot at state	5 (rounds per minute)	9 (rounds per minute)

1. Decision Variables

- **M777A2 Emplacement:** Defined as the time it takes to emplace a M777A2 howitzer or battery in a gun position and become FIRECAP. The simulation assumes all emplacements are conducted with DFCS. Emplacement times are based on the proficiency level of the howitzer section.

- **M777A2 Displacement**: Defined as the time it takes to displace a M777A2 howitzer or battery from a gun position. Displacement times are based on the proficiency level of the howitzer section. All howitzer sections are assumed to be "light on the deck" a phrase which means only fire essential equipment is off the gun truck and ammunition is pulled from the ammunition truck and not set on the deck.

- **M777A2 Time In Position (TIP)**: Defined as the time a M777A2 howitzer or battery spends in a gun position after taking enemy IDF. The accuracy of enemy IDF typically drives this decision, but all IDF fire in MANA is considered accurate. Therefore, the researcher is unable to differentiate between accurate and inaccurate fire in the decision-making process for this variable.

- **Hits to Kill**: Defined as the number of hits required for a howitzer to become a casualty. For the M777A2, this value comes from the utilization of terrain for cover from IDF, the armor thickness of the howitzer, and the personal protective equipment of the gun crew.

- **Rate of Fire**: Defined as the rounds per minute fired by a howitzer during the Shot At or Squad Shot At state. This state assumes that the artillery agents increase the rate of fire while firing on enemy IDF units. MANA defines the rate of fire as "shots per second." For example, 6/100 represents a rate of fire of 3.6 rounds per minute (RPM).

2. Noise Variables

The researcher chose to exclude noise variables from the experiment. Excluding the Red variables allows the researcher to focus on the impact of employment options for Blue while avoiding complexity in the results. Open source data defines the range of input variable values. The variables remain constant between the battery and distributed scenarios.

- **2S19-Msta-S Emplacement**: Defined as the time it takes to emplace the howitzer and become FIRECAP. Set at 120 seconds for both scenarios.

- **2S19-Msta-S Displacement**: Defined as the time it takes to displace from a gun position. Set at 30 seconds for both scenarios.

- **2S19-Msta-S TIP**: Defined as the amount of time the battery remains FIRECAP in the current gun position after taking enemy IDF. Set at 500 seconds for both scenarios.

- **2S19-Msta-S Hits to Kill**: Defined as the number of hits required to destroy a howitzer. Set at three for both scenarios.

- **2S19-Msta-S Rate of Fire**: Defined as the rounds per minute fired by the howitzers. Set at four rounds per minute while firing at infantry units and six rounds per minute while firing at IDF units.

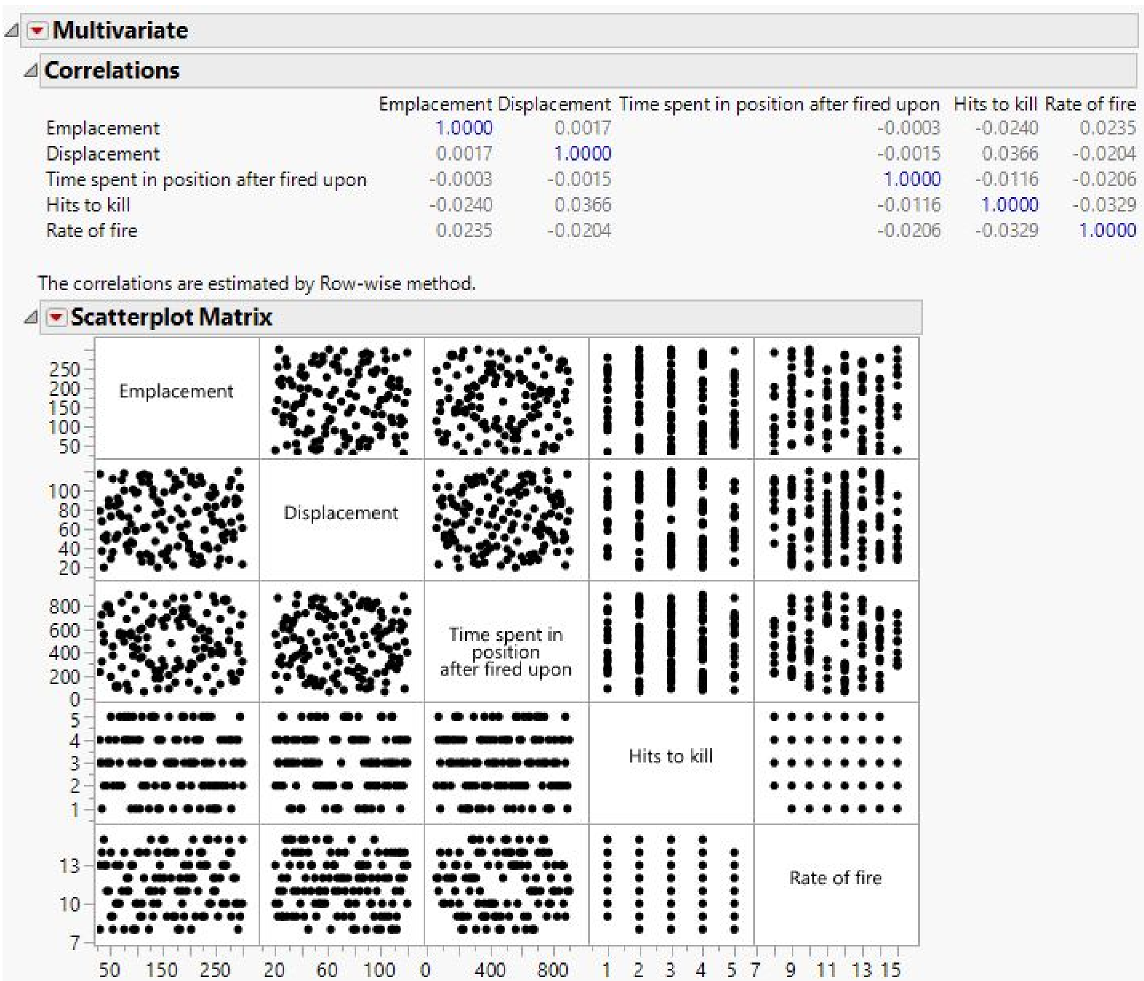
C. DESIGN OF EXPERIMENT

The experiment follows an iterative approach. The researcher creates the scenarios, runs the simulation, observes the results, and returns to each step to refine the process. The experiment is reviewed and debugged to achieve accuracy and consistency in the results. The experiment is run several times to make refinements in the variables of interest. Once the experiment meets the goals of the study, the design space displays the results. The goal for the experiment design is to fill the design space and evaluate the correlation between factors, and the tool for this is the NOLH.

D. THE NEARLY ORTHOGONAL LATIN HYPERCUBE

This study uses the NOLH is used to create the design of the experiment. The NOLH tool helps minimize the correlation between factors and the overall number of design points. A maximum pairwise correlation below 0.05 is desired to achieve orthogonality and allow for further analysis of the uncorrelated factors with other models (Hernandez, Lucas, & Carlyle, 2012). The NOLH workbook is widely used for computer simulations conducted at the Naval Postgraduate School because of its ease of use and its availability through the SEED Center. For a more detailed explanation of the NOLH tool, refer to the references or the SEED Center website at https://my.nps.edu/web/seed/software-downloads.

The minimum and maximum values for the five decision variables are inserted into the NOLH template to produce two 65 design point matrices that are rotated and stacked into one 129 design point matrix. JMP Pro Statistical Discovery Software version 15.0 takes the matrix, in excel format, to evaluate the pairwise correlations values between factors and the space-filling properties of the design.



Multivariate

Correlations

	Emplacement	Displacement	Time spent in position after fired upon	Hits to kill	Rate of fire
Emplacement	1.0000	0.0017	-0.0003	-0.0240	0.0235
Displacement	0.0017	1.0000	-0.0015	0.0366	-0.0204
Time spent in position after fired upon	-0.0003	-0.0015	1.0000	-0.0116	-0.0206
Hits to kill	-0.0240	0.0366	-0.0116	1.0000	-0.0329
Rate of fire	0.0235	-0.0204	-0.0206	-0.0329	1.0000

The correlations are estimated by Row-wise method.

Figure 8. Correlation Matrix and Scatterplot of the Decision Variables

Figure 8 depicts the correlation matrix and the scatterplot matrix for the five decision variables. The correlation values correspond to the intersection of the variables listed in the columns and rows. The correlation values of 1 correspond to a variable correlated to itself and are ignored. The largest correlation value in the matrix, 0.0366, corresponds to the relationship between Displacement and Hits to Kill. The scatterplot matrix is a visual representation of the correlations between variables and displays the space-filling properties of the design. Analysis of the matrix concludes no linear relationships between variables and a good space-filling effect for the design.

E. EXPLORATION DESIGN

Table 1 lists the five variables used in the exploratory design. The NOLH yields 129 design points, 65 from each scenario with the middle duplication removed, from the five variables and the range of the minimum and maximum values. Each design point is simulated 50 times to yield 6,450 runs per scenario for a total of 12,900 simulated battles. There are two possible stopping conditions for each scenario. The first stopping condition is six casualties for Squad 6, the Red force artillery battery. The second stopping condition is the simulation reaching the maximum number of time steps set at 75,000. The researcher chose 75,000 as the maximum time steps to ensure that either the first stopping condition is met or the destruction of the entire Blue artillery battery.

F. RUNNING THE EXPERIMENT

To run the experiment, the researcher provides the SEED Center with the base scenario eXtensible Markup Language (XML) files and the DOE file in comma-separated value (CSV) format. The SEED Center runs through various steps to run the simulation and provide the outputs to the researcher via excel files. In the absence of a formal reference, an explanation of the process was provided to the researcher in an email correspondence:

> The following section describes how the SEED Center configured and executed the DOE. The base case MANA scenario, in XML format, and the DOE file, in CSV format, were entered into a software program called XStudy, written by SEED Center Research Associate Steve Upton. XStudy enables the user to map each column in the design file to a specific parameter element in MANA, using XPaths. An XPath is a reference to a specific location in an xml file. Other details about the study design, such as the version of MANA and the number of replications per design point, are also entered into this tool, yielding a single “study.xml” file. This study file is used by another program called oldmcdata, also written by SEED Center Research Associate Steve Upton, which programmatically modifies

> the MANA XML file, producing a separate XML scenario file for each design point. An open source software package called HTcondor, available from the University of Wisconsin (https://research.cs.wisc.edu/htcondor/), is used to distribute and manage the MANA jobs in parallel across a set of available processors. The oldmcdata software creates the set of submit.dat files needed by condor, one for each design point job. A job consists of a set of replications for one design point excursion. Upon completion of the runs, oldmcdata includes a data postprocessor that combines MANA output from the individual summary and step files into one csv file, ready for use with any data analysis software package. This output file contains input factor settings from the DOE, the random number seed, and selected outputs for each replication. (M. McDonald, email to author, February 25, 2020)

The experiment extracts the design points, force casualty data, squad casualty data, run time steps, and injury data. The researcher uses the extracted data to create new variables to analyze survivability in the next chapter.

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V. ANALYSIS

This chapter discusses how the experiment data is collected, compiled, and analyzed to address the research questions.

A. DATA COLLECTION

Once the high-performance computers run the simulations, software farms the data and output the data into CSV files that are provided to the researcher. The experiment yields two CSV files, one for the battery scenario and one for the distributed scenario. The CSV file organizes the data by run and seed number. The outputs consist of overall force casualty data and squad casualties for each run.

MANA allows the user to select up to nine types of data outputs: Step by Step Data, Casualty Location Data, Agent State Data, Detection Data, Multi-Contact Detections, Positions, Red Detections per Step, Comms per Step, and First Enemy Detections (McIntosh et al., 2007). For example, the Casualty Location Data includes nine outputs: position of agent’s death, time of death, name of dead agent, squad number of dead agent, sub-squad number of dead agent, identification number of dead agent, state at death of dead agent, identification of killer, and class of weapon used by the killer (McIntosh et al., 2007). Force and squad casualty data are the only outputs relevant to the scope of the study.

B. MEASURE OF EFFECTIVENESS

This study compares the survivability of two operational employment methods. The study defines survivability as the measure of effectiveness to answer the research questions. The research questions are restated as follows:

- Which employment method from the two tested increases survivability against a near-peer adversary?
- Which movement and tactical considerations have the most significant impact on survivability within the two employment methods?

Traditional ratios such as the Loss Exchange Ratio or Combat Power Loss Exchange Ratio are not used in this study because the additional forces included in the simulation are not the objects of interest. The ratios incorporate the entire force size into the equation and thus incorporate noise caused by those units' casualties. The artillery forces casualty numbers, which are only caused by other artillery units, are the focus of the analysis.

The definition of survivability starts with the mission of the field artillery, which is "to destroy, neutralize, or suppress the enemy by cannon, rocket, and missile fires and to help integrate all fire support assets into combined arms operations" (USMC, 2016, p.1-1). The author interprets survivability for a field artillery cannon battery as accomplishing the mission while simultaneously undergoing efforts to increase the battery's chance of survival. Simply put, the desired end state is to eliminate the Red artillery battery while minimizing friendly casualties. The first analysis focuses on whether the Blue force won the scenario, then a separate analysis discusses decision variables that work to minimize friendly casualties.

To define survivability, this study uses the results to declare a Blue force victory through two conditions: the simulation stopping condition and the simulation time steps. Blue wins with the destruction of the entire Red force artillery squad within the 75,000-maximum number of time steps. Blue loses if the Blue artillery is destroyed and any Red forces remain after the simulation reaches the maximum number of time steps. A binary variable called Blue Force Win has a value of 1 for a Blue victory and 0 for a Blue loss. The Blue Force Win variable is used to compare the results from the Battery and Distributed scenarios.

C. DATA PREPARATION

The analysis starts with the combination of the output files from the two scenarios into one spreadsheet. A new variable labeled Tactic describes the employment option used in the simulation, whether battery or distributed. The output organizes the results by design point and tactic. The analysis disregards casualties for infantry and support units to maintain focus on the artillery units to answer the research questions. JMP is the primary data analysis tool for the results.

The researcher organizes the data in JMP by tactic and design point. A summary table groups the 50 simulation runs into their single design points. Summary statistics show the mean and standard deviation for the selected output metrics by design point. The resulting table consists of 258 rows with 129 design points per tactic.

D. SURVIVABILITY ANALYSIS

1. Blue Victory Analysis

This analysis relies on JMP's recursive partition platform to explore the relationship between the decision variables and the Blue Force Win variable. The partition tree analyzes the X or explanatory variables to separate the factors that best predict the Y or response variable. The model creates a decision tree showing splits in the explanatory variables that best explain the model. For this tree, the R-squared value and the mean values for the splits are the objects of interest. A partition tree is run with the mean (Blue Force Win) as the response variable and Tactic with the five decision variables as the explanatory variables or predictors. Figure 9 shows the partition tree for this model.

For the partition tree, the higher mean value between the two explanatory variables represents the better split. A low mean value depicts the worse option based on the split.. Green boxes are placed around the factors representing a good split and red boxes are placed around the bad splits.

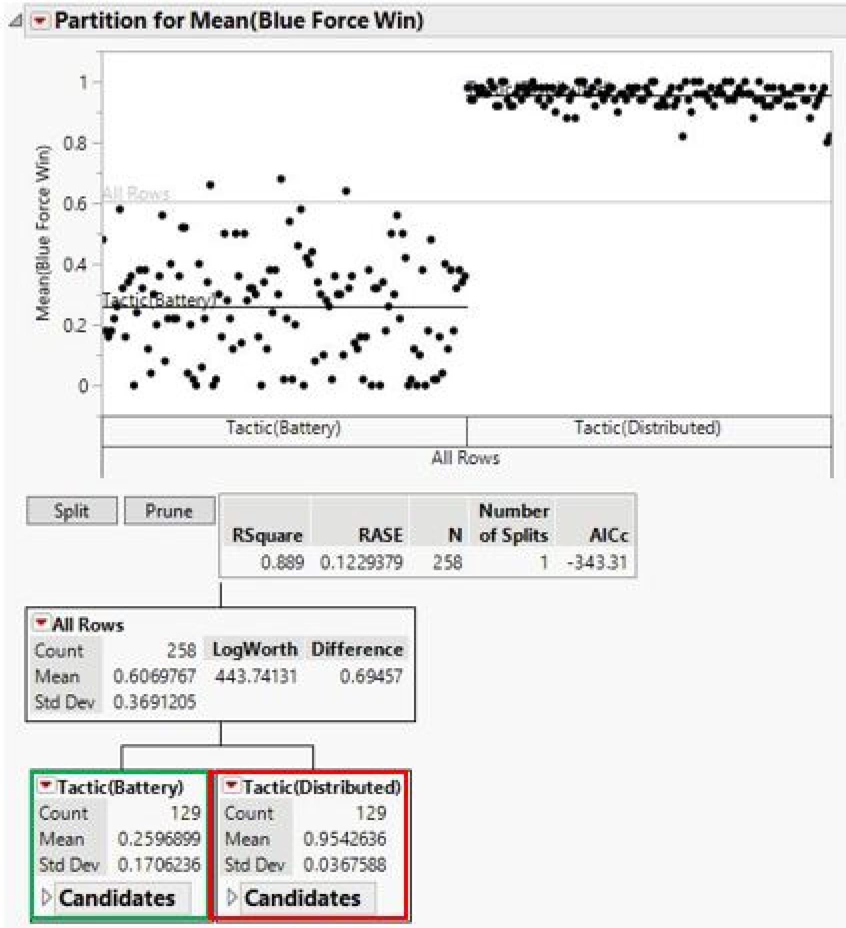
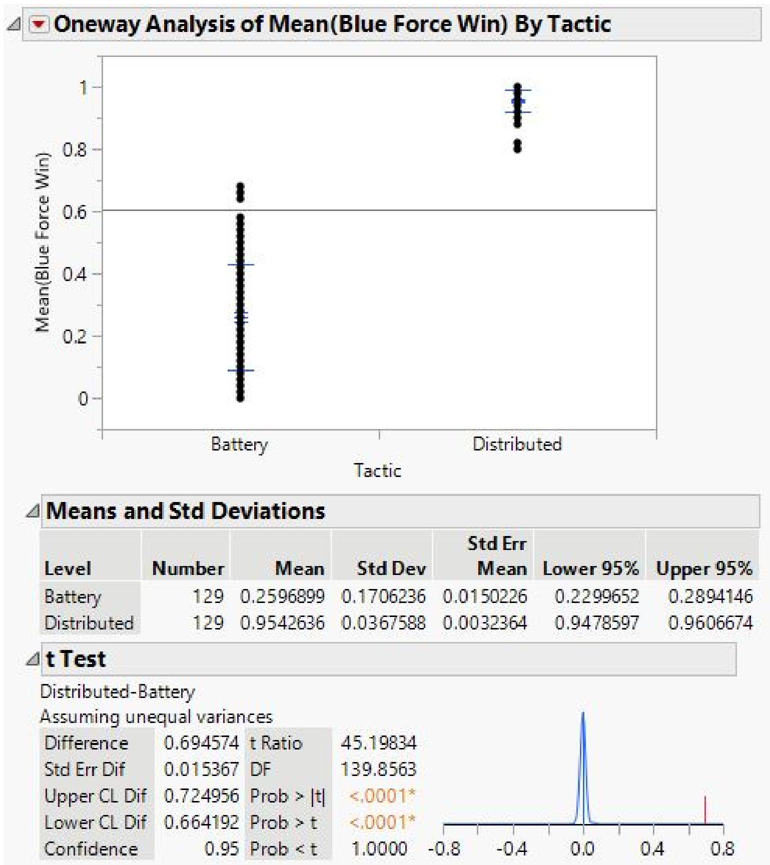


Figure 9. Mean (Blue Force Win) Partition Tree

The first split happens at the Tactic variable. After one split, the R-squared value for the mean Blue Force Win is 0.889. Interpret this value as the choice of tactic explains 89 percent of the variation in the mean value for Blue Force Win. The mean value for Blue Force win after the split is 0.6069, with a standard deviation of 0.3691. There are 129 observations for both tactics to represent the 129 design points per scenario that include the 6,450 runs per and 12,900 runs in total. The battery tactic results in a mean of 0.2596 and a standard deviation of 0.1706. The distributed tactic results in a mean of 0.9542 and a standard deviation of 0.0367.

Figure 9 shows the significant difference between the two employment options when considering a Blue force victory. The mean value for the distributed tactic explains that the Blue force won 95 percent of the time (6,155 wins divided by 6,450 runs) while the mean value for the battery tactic means that the Blue force won 25 percent of the time (1,675 wins divided by 6,450 runs). The difference between the two tactics is approximately 70 percentage points. A t-test explores whether the difference is statistically significant.



Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Battery	129	0.2596899	0.1706236	0.0150226	0.2299652	0.2894146
Distributed	129	0.9542636	0.0367588	0.0032364	0.9478597	0.9606674

Difference	0.694574	t Ratio	45.19834
Std Err Dif	0.015367	DF	139.8563
Upper CL Dif	0.724956	Prob > |t|	<.0001*
Lower CL Dif	0.664192	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000

Figure 10. Oneway Analysis of Mean (Blue Force Win) by Tactic

Figure 10 shows the results of a Oneway analysis in JMP to explore the significance between the mean values for Blue Force Win by Tactic. At the 95 percent confidence level, the difference between the means is statistically significant. The t-ratio of 45 is significantly higher than the 1.96 used a threshold value for the 95 percent confidence level. The Oneway analysis shows that the differences between the battery and distributed means is statistically significant.

Figure 9 shows the dominance of the distributed tactic over the battery option. Both tactics use the same five decision variables to dictate the unit's behavior and tactics in the simulation. Input values and behavior remain the same for Blue's non-artillery agents as well as the entire Red force's behavior and tactics. The employment option represents the only difference between the two scenarios. The employment tactic alone results in a 70-percentage point difference in the chance of victory.

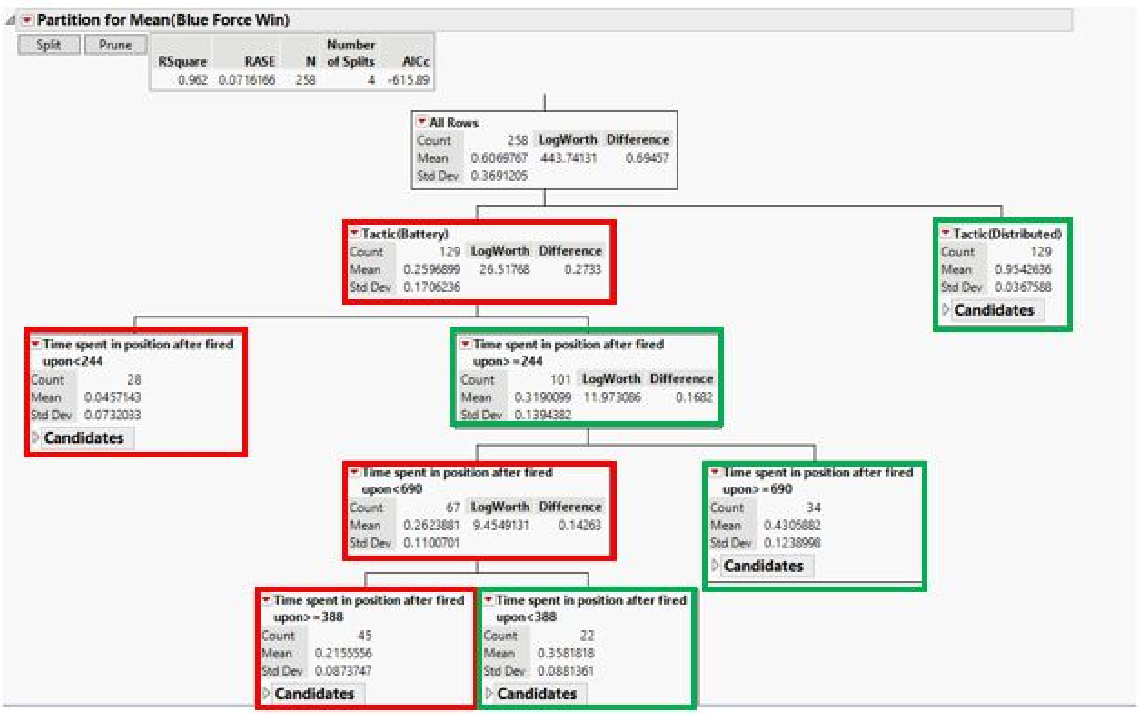


Figure 11. Mean (Blue Force Win) Partition Tree with Additional Splits

Further analysis of the partition tree shows the dominant decision variable in the simulation. Figure 11 shows the partition tree after four splits. The next factor the tree splits is the Time in position. The three subsequent splits happen on the same factor and take place underneath the battery tactic. Figure 11 shows the best option is to remain with the distributed tactic even after three refinements to the most dominant of the five decision variables. The model R-squared value increases to 0.962 from 0.889 after four splits. The high R-squared value means that after only four splits 96.2 percent of the model is explained solely by Tactic and TIP. The other four decision variables could, at a maximum, explain only 3.8 percent of the variation in the model. Even after four splits, the initial best split at distributed remains the highest mean value. However, the mean value under battery increases from 0.2596 to 0.4305 with a standard deviation of 0.1238.

After four splits, Figure 11 shows remaining in a gun position longer with the battery employment option leads to an increase in the mean chance of victory. The last good split happens at TIP greater than or equal to 690 seconds, which corresponds to 11.5 minutes. Staying in a position longer after taking IDF seems counterintuitive to survivability, but the data shows the opposite. In this scenario, the longer the battery stays in a position translates to more opportunities to fire on the Red artillery battery to cause casualties whereas the alternative option is to displace to an alternate position. It is important to note that the battery is still taking IDF while in the act of displacing. Further analysis of the dominant decision variables' impact on the chance to win offers additional insight into the simulation.

2. Battery Win Analysis

The next step is to analyze how the decision variables impact Blue's victories with the battery tactic. Figure 12 shows the partition tree for the mean (Battery Win) with the decision variables as the predictors. After four splits the R-squared value for the model is 0.718. The best split with the highest mean value for Battery Win happens after the second split at greater than or equal to 690 seconds for TIP. Figure 12 explains that the decision variables, after four splits, help explain 71.8 percent of the variation in mean (Battery Win).

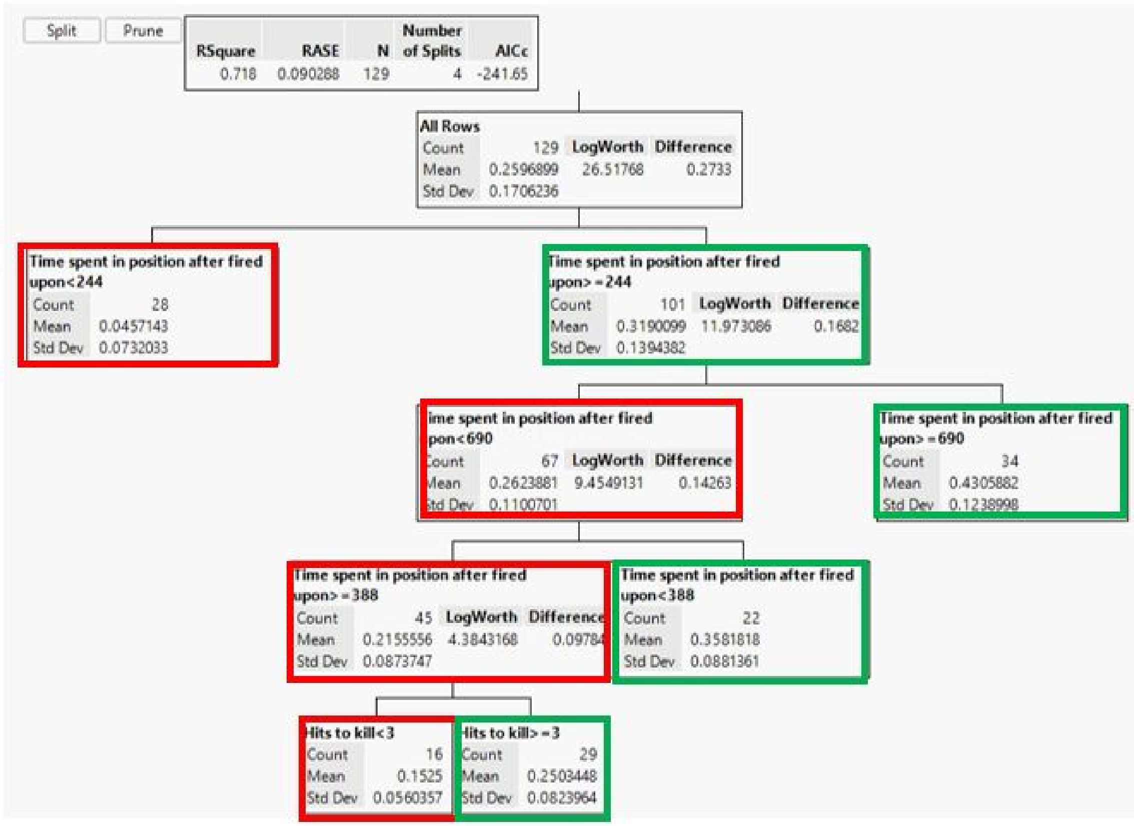


Figure 12. Mean (Battery Win) Partition Tree

Figure 12 shows the dominance of the TIP variable in a contour plot. The TIP variable is on the Y axis and the Displacement variable is on the X axis. The colors in the middle of the graph represent the data points for the mean (Battery Win) variable. The Battery Win variable represents the number of Blue force victories exclusively in the battery scenario. The contour plot shows how impactful the TIP variable is to the mean (Battery Win) variable. Red represents a high mean value, while blue represents low mean values of Battery Win. The graph depicts most of the red contour or high mean values for Battery Win at the top of the graph between approximately 680 to 900 seconds.

There is a portion of the graph not included in the 680 to 900 second window with high mean values for Battery Win. Given a battery stays in a position less than 680 seconds, the battery should stay in the position less than approximately 380 seconds but no less than 240 seconds. Durations between 380 and 680 seconds and the values less than 240 seconds correspond to significantly low mean values for Battery Win. Overall, Figure 12 highlights the battery's higher chance of victory, the longer it occupies its current position after taking enemy IDF.

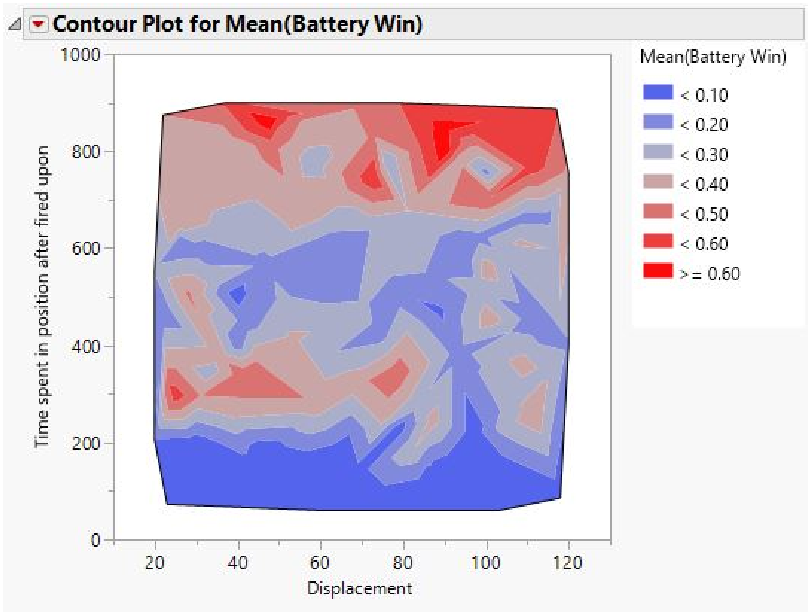


Figure 13. Contour Plot for Mean (Battery Win)

3. Distributed Win Analysis

The decision variables explain very little in the mean (Distributed Win) variable. Figure 14 shows the partition tree with the decision variables as the predictors and the mean (Distributed Win) as the response variable. After four splits, the R-squared value is 0.302, meaning that the decision variables explain approximately 30 percent of the variation in the chance of a victory for the Blue distributed force. The initial mean value for Distributed Win is 0.9542, with a standard deviation of 0.0367. After the fourth split, the mean value increases only 2.14 percentage points to 0.9756, with a standard deviation of 0.0211. The model shows how little the decision variables impact the mean chance of victory in distributed operations.

The data explains that distributed operations increase the chance of victory just based on the employment method. The decision variables, which represent movement and tactical considerations, are less impactful to the chance of victory than the employment method alone. There are several explanations for this conclusion that cannot be uncovered by the model. First, distributed howitzers force the enemy artillery unit to choose between six targets instead of one large battery target. A distributed howitzer can take advantage of a smaller gun position by utilizing the tree line for protection without area echo concerns. Area echo is the term used to describe the area in front of the howitzer that must be clear of friendly units. Area echo is a major factor in the selection and set up of gun positions with battery employments. For example, gun positions large enough for a battery emplacement rarely allow for the battery to utilize the tree line. The direction the howitzer is laid, called the azimuth of fire, commonly conflicts with the position of the other howitzers because of area echo considerations. Simply put, a distributed howitzer maximizes the protection offered by the position without any friendly area echo concerns.

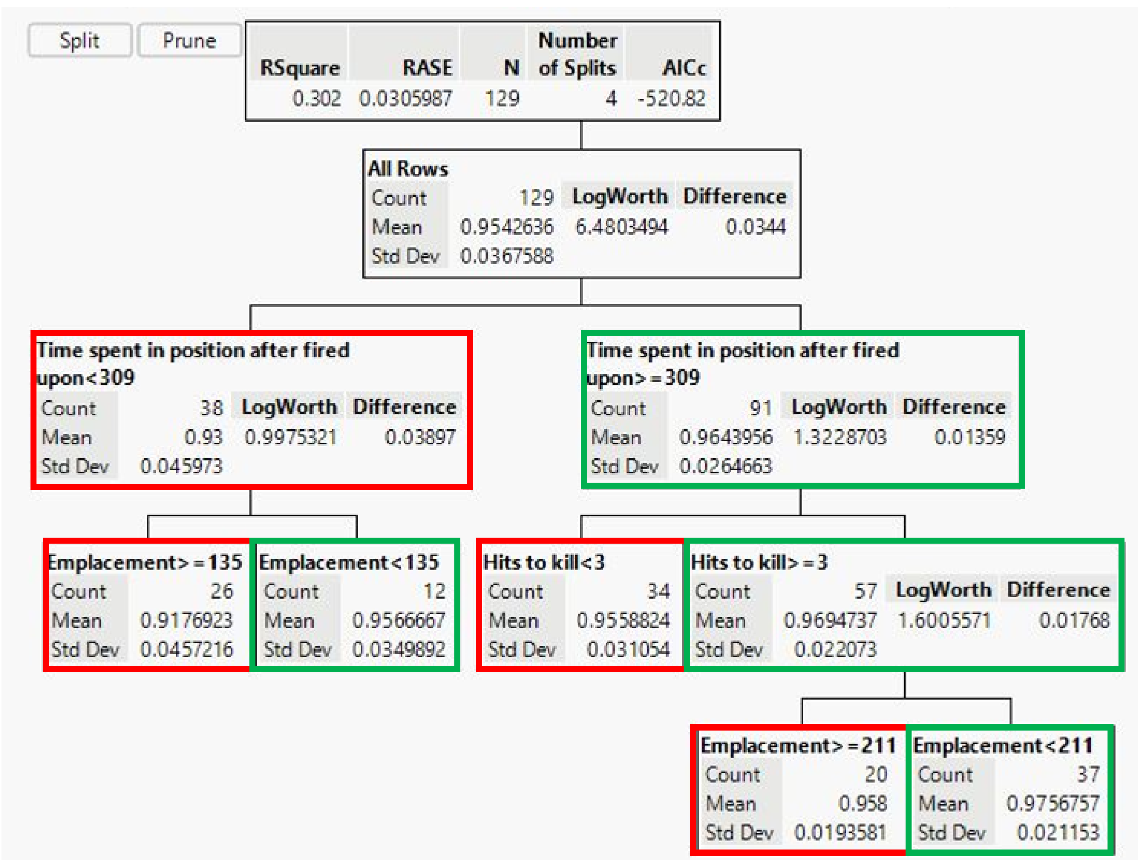


Figure 14. Mean (Distributed Win) Partition Tree

4. Scenario Win Comparison

The magnitude of the decision variables impacts on the chance of winning for the employment options is significantly different. Figure 15 shows the R-squared values after each of the four splits for both employment tactics from Figures 12 and 14. The influence of the decision variables on the battery employment option is wide-ranging and helps explain a significant portion of the variation in the model. The decision variable influence for the distributed option is significantly less overall and has a smaller range than with the battery employment option.

The R-squared value for mean Distributed Win starts low and remains low. The low R-squared value explains that the five decision variables hardly explain the variation for the chance of victory in the distributed scenario. Rather, the low R-squared value means that the mean Distributed Win variable is more susceptible to robust errors in the model excluding the five decision variables. In layman's terms, this means that distributed operations are heavily influenced by the overall scenario and possibly the Red force actions more than the Blue forces own actions.

The models help inform a battery commander what to expect in each employment option. In distributed operations, a commander should focus on training sections to exploit gun positions for protection. For battery operations, movement and tactical considerations weigh heavier on the chance of victory, and the commander should focus on training the battery to react confidently under enemy IDF so that the battery is able to stay in the position longer and accurately engage the enemy.

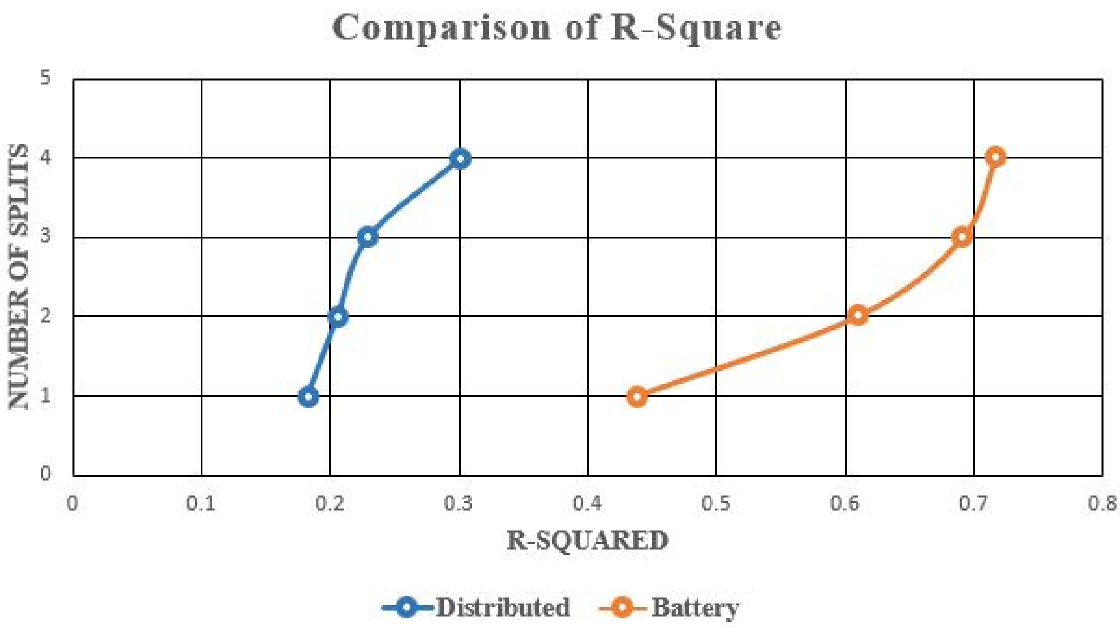


Figure 15. Comparison of R-Square for Mean (Battery Win) and Mean (Distributed Win)

E. CASUALTY ANALYSIS

The second part of the definition of survivability addresses the need to minimize friendly casualties. Figure 16 depicts the distributions for the mean number of Blue casualties suffered by the artillery squads in the battery and distributed scenarios. The mean value for the battery scenarios is 5.1866, with a standard deviation of 0.6609. The mean value for the distributed scenarios is 0.1992, with a standard deviation of 0.2388. Just like the chance of victory, a significant difference exists in the mean value of the variables between the two employment options. Distributed employment results in a significantly smaller mean number of casualties compared to battery employment.

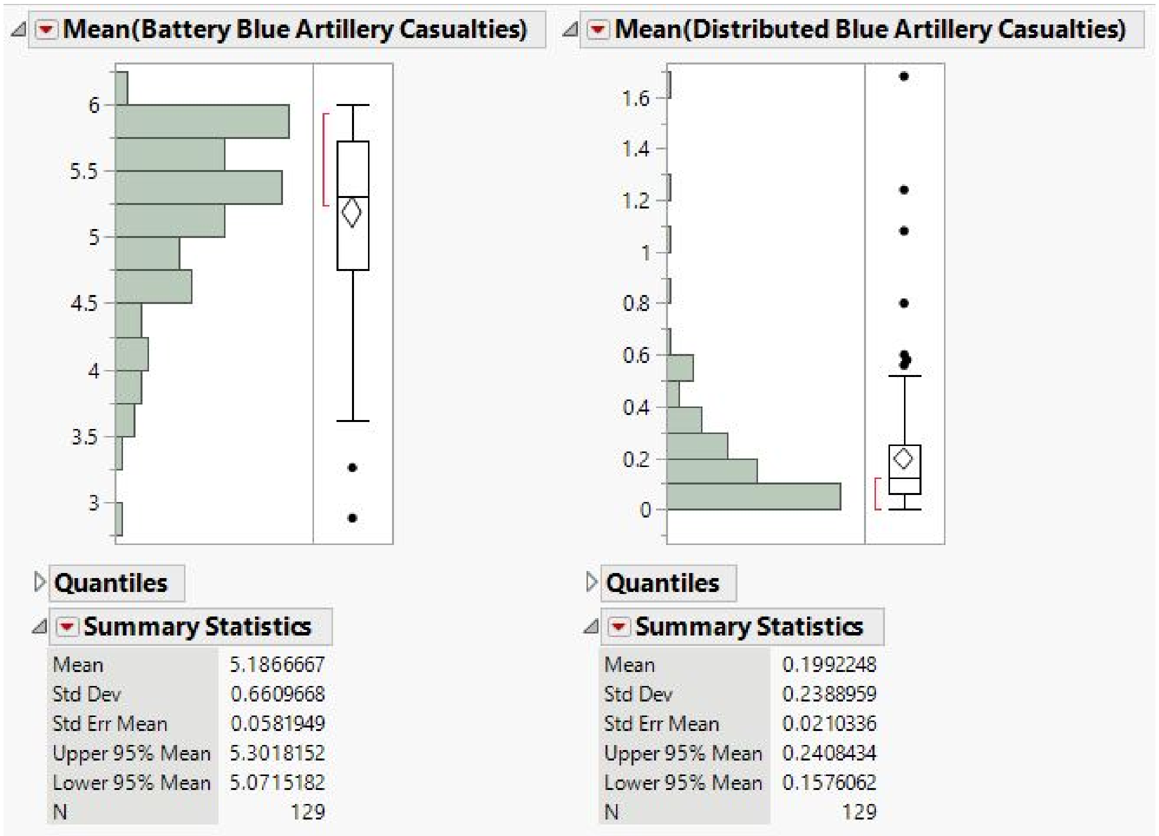


Figure 16. Distribution of Distributed and Battery Blue Artillery Casualties

1. Blue Battery Artillery Casualties

Figure 17 shows the first four splits of a partition tree with the five decision variables as the predictors and the mean (Battery Blue Artillery Casualties) as the response variable. A good split in this tree is the option with the lowest mean value to represent a smaller number of casualties suffered by the Blue artillery battery. The R-squared value increases 14.8 percentage points from the initial split to the fourth split. The initial R-squared value is 0.584, and the R-squared value after the fourth split is 0.732. The tree initially splits again at the dominant decision variable identified in the previous partition tree. The good split at greater than or equal to 690 seconds for the TIP remains the best mean value after subsequent splits. The mean value for the best split is 4.3452, with a standard deviation of 0.5543. The tree splits again at the dominant variable, Hits to kill and lastly at Emplacement. Even though the additional splits increase the R-squared value, the best option representing the one with the lowest mean number of Blue artillery casualties is the best option from the first split. The dominant factor remains significant over the other four decision variables, even for casualties in the battery scenario.

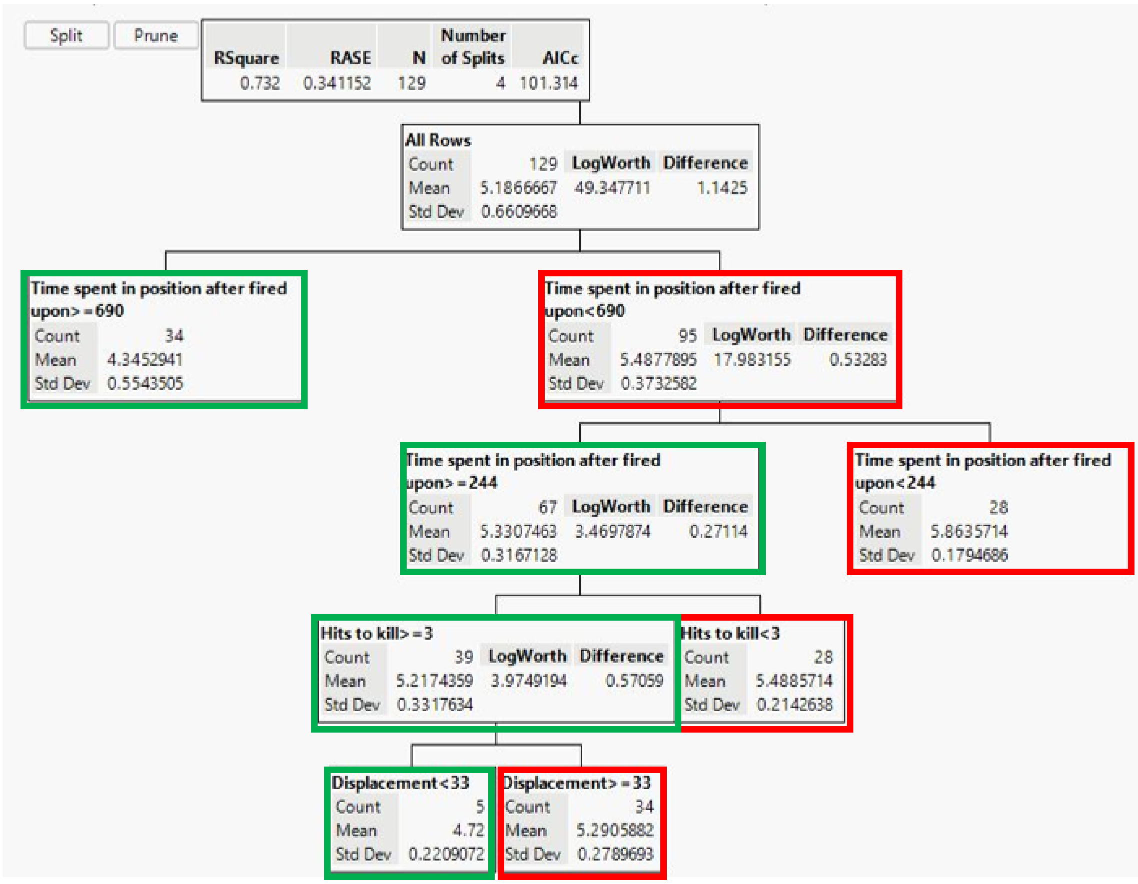


Figure 17. Partition for Mean (Battery Blue Artillery Casualties)

2. Blue Distributed Artillery Casualties

Figure 18 shows the first four splits of the partition tree with the five decision variables as the predictors and the mean (Blue Distributed Artillery Casualties) as the response variable. The results of this analysis show a significant presence of unexplained variance in the model. The R-squared value starts low and remains low with additional splits. The mean value of casualties represents a fraction of a casualty instead of several casualties like the value seen in the battery analysis. Figure 18 shows the minimal impact of the decision variables on the mean value for Blue Distributed Artillery Casualties.

However, the TIP variable remains dominant and is the first variable the tree splits on. A higher TIP is associated with a lower mean value for casualties with a mean of 0.1720 and a standard deviation of 0.1728 compared to the bad split mean value of 0.7566 with a standard deviation of 0.5845.

This split represents an idea that is contrary to the opinion of artillery subject matter experts. When the researcher discussed reactions to enemy IDF for the distributed howitzers, senior enlisted Marines recommended that the distributed howitzers should displace immediately. This idea comes from the notion that distributed howitzers displace faster than howitzers operating within a battery because of their smaller logistical footprint. Additionally, the displaced distributed howitzer is less detrimental to the FIRECAP of the battery since other howitzers remain in place in contrast to battery employment where the battery loses the FIRECAP when it displaces. Nonetheless, there are six observations to support the mean value of 0.7566 for Blue distributed artillery casualties in the model.

In Figure 18, subsequent splits start to incorporate the other four decision variables. The next split happens at two hits to kill then 296 seconds for TIP. The fourth split happens at greater than or equal to and less than three hits to kill. The good split occurs at greater than or equal to three hits to kill with a mean value of 0.0586 and a standard deviation of 0.0424. The R-squared value for the model increases from 0.268 to 0.519 or 25.1 percentage points after the fourth split. This tree shows that the five decision variables explain only half of the variation in mean casualties for the Blue artillery squad operating distributed. Further analysis outside this study would be required to determine the other 49 percent of the variation in the model.

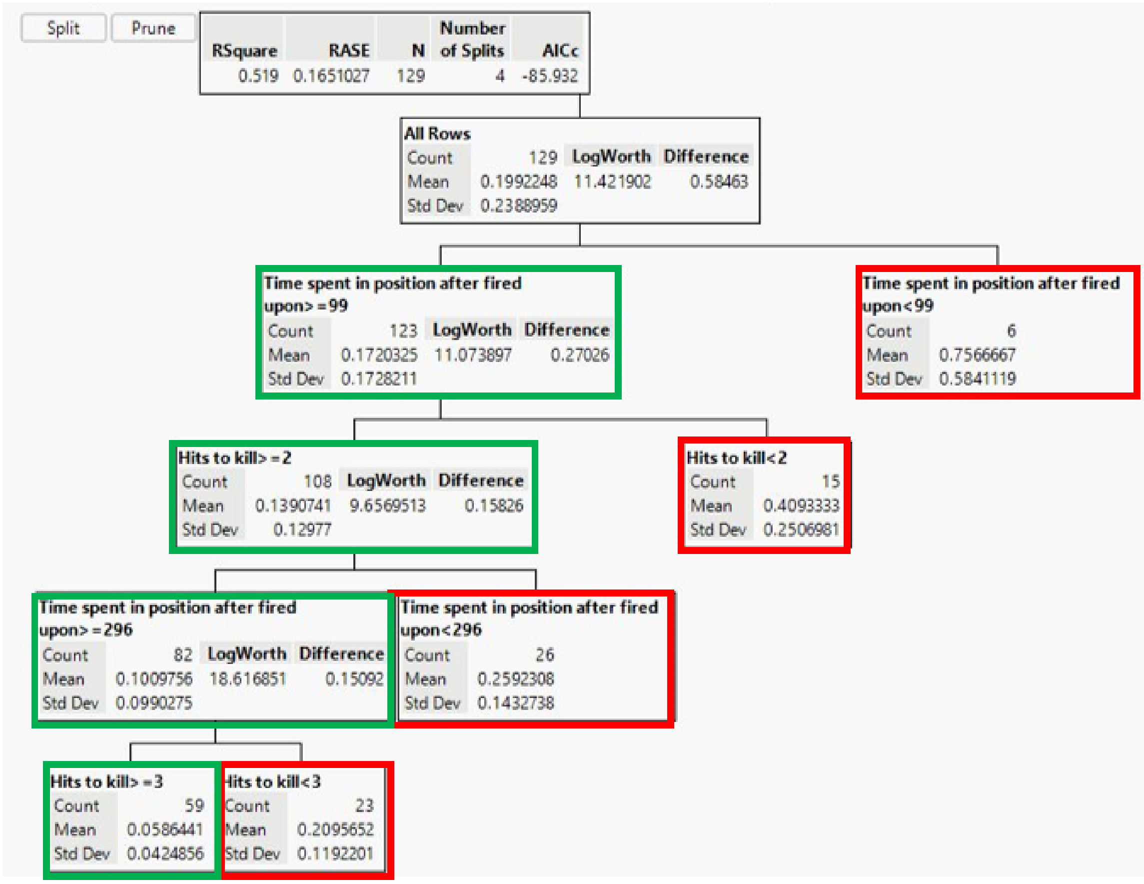


Figure 18. Partition for Mean (Blue Distributed Artillery Casualties)

3. Scenario Casualty Comparison

The decision variables hold more weight in the casualty analysis. Figure 19 shows the R-squared comparison for the mean (Blue Battery Artillery Casualties) and the mean (Blue Distributed Artillery Casualties) after four splits on the partition tree. The decision variables explain more variability for the battery model than the distributed model, but unlike the previous comparison, the variables explain significantly more of the variation for the distributed model. The data shows that the decision variables have a substantial impact on the mean number of casualties for both employment tactics. That conclusion appears practical based on the decision variables. Two of the five variables specifically focus on safeguarding howitzers from enemy IDF. Emplacement and Rate of Fire relate more to lethality. The enemy does not know where an artillery unit is during an emplacement and the Rate of Fire focuses on inflicting casualties rather than preventing them. The exception however is the TIP variable. The variable dominants both the win and casualty analysis and appears to be a tactic that works to minimize casualties through increased lethality. The saying, "the best defense is a good offense" rings true in this scenario.

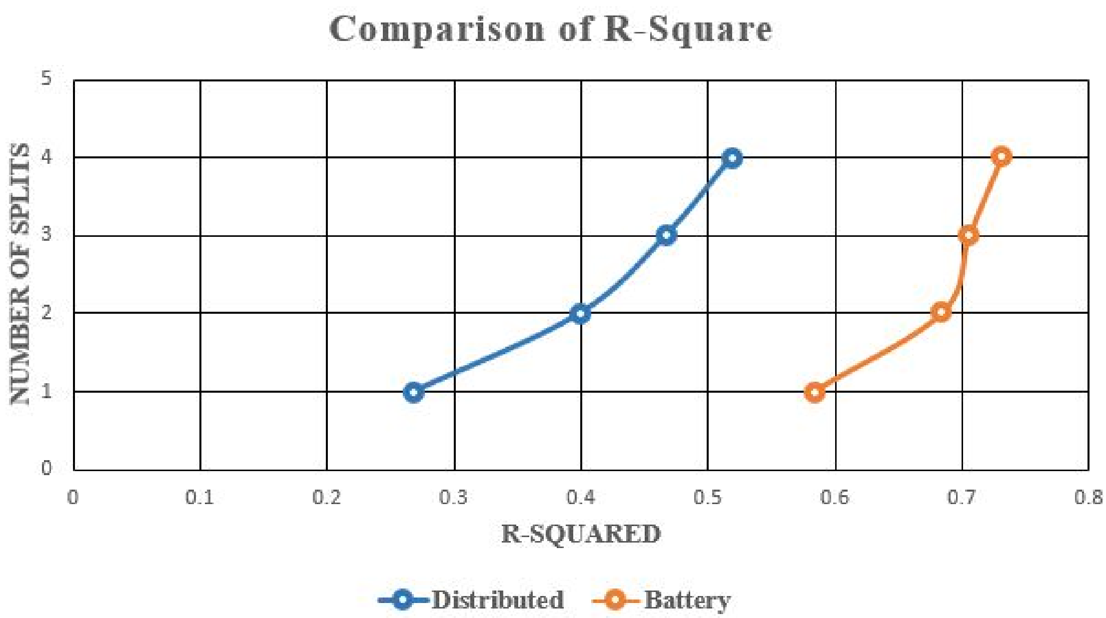


Figure 19. Comparison of R-Squared for Mean (Battery Blue Artillery Casualties) and Mean (Distributed Blue Artillery Casualties)

F. CONCLUSIONS FROM THE SIMULATION EXPERIMENT

The experiment provides several key insights into an artillery on artillery counter-battery fight. However, it is important to note that the decision variable values identified by the partition trees should not be taken literally. A commander should not take a single value from the best split for the Time spent in position and instill it as doctrine. The values merely help explain variation in the model and should be taken in the general sense when considering decisions.

The main conclusion from the simulation is that survivability and lethality work in tandem. Throughout the survivability analysis, TIP remained the most dominant of the decision variables. While staying in a position longer may appear to run counterintuitive to minimize friendly casualties, doing so increased the battery or howitzer's lethality. The increased lethality resulted in more victories and simultaneously fewer friendly casualties.

Next, distributed operations are less impacted by controllable and uncontrollable factors. The researcher identified the decision variables based on the criteria used to evaluate artillery weapon systems and their capabilities. The simulation shows that the decision variables clung to by critics and supporters alike are not that important after all. The victory analysis showed that the just the distributed tactic alone accounted for a substantial part of the variation in the Blue Force Win model. The artillery communities focus should not be outward on new systems but inward on tactics.

Decision variables heavily impact the success of battery operations in a counterbattery fight. The decision variables played a substantial role in maximizing the chance of victory and minimizing friendly casualties. This conclusion spotlights the proficiency of the battery staff. A battery employment method centralizes the decision making to the leaders of the battery. The simulation shows through the input values for the decision variables that small variations lead to significant swings in either direction. Simply put, a one-minute difference between the time spent in a position could mean life or death in a counter battery fight.

VI. CONCLUSIONS

A. INSIGHTS INTO THE RESEARCH QUESTIONS

Technological upgrades to the M777A2 resulted in enormous strides in its capability over the last decade. Still, current doctrine does not capture the full spectrum of the M777A's capabilities. Concurrently, other newly developed artillery systems and projectiles made impacts on battlefields across the world. Most notable is Russia's use of thermobaric projectiles and unmanned aerial systems by their artillery forces. The destruction witnessed at Zelenopillya in July of 2014 sparked an intense conversation of survivability among the artillery community. As a result, calls for the abandonment of the M777A2 grow louder and more frequent. Critics use several metrics to highlight the superiority of self-propelled artillery systems over the M777A2. However, those metrics are commonly used to evaluate artillery systems and not the tactics used to employ the systems.

This study incorporated the metrics used to compare artillery system into an evaluation of tactics, specifically employment options. The M777A2's DFCS opens the door for an alternative type of howitzer employment. DFCS allows for the distribution of M777A2's across the battlefield outside the traditional battery or platoon employment options. To evaluate the impact of distributed operations, this thesis uses survivability as the main measure of effectiveness. The results from the simulation found that now only did distributed operations substantially increase survivability, it also found that the metrics used by critics to compare weapon systems had little to no impact on the survivability of artillery units in either employment option.

B. RESEARCH SUMMARY

1. Insights

- **Distributed employment**: Distributing howitzers across six-gun positions led to a 70-percentage point higher chance of victory in the simulation. Distributed howitzers suffered less casualties and were rarely destroyed all together by the enemy artillery unit. Traditionalists argue that the distribution of howitzers comes at sacrificing the battery's ability to mass fires. The simulation results do not support this argument. Based on the simulation results. distributed howitzers in the simulation inflicted casualties on the enemy artillery unit more frequently and faster than the howitzers operating as a battery. Metrics used to measure the proficiency of a howitzer section such as emplacement time and displacement time had little impact on the survivability and effectiveness of distributed howitzers. Distributed howitzers force enemy artillery unit to choose which of the six howitzers, if all locations are known, to engage. Distributed employment forces the enemy artillery unit into a trade-off decision. If the enemy unit masses on one distributed howitzer then it leaves itself open to IDF from the other five distributed howitzers. A high degree of accuracy is required to hit a lone distributed howitzer, so if the enemy artillery unit decides not to mass on a single target it increases its chances of missing the target.

- **Battery employment**: Criticism of the M777A2 holds true when the howitzers employ as a centralized battery. When employed as a battery the Blue artillery force suffered substantially more casualties than the distributed force. The decision variables largely impacted the survivability of the battery. However, the battery succeeded when it stayed in a position longer to engage the enemy artillery unit. Doing so stripped out the impact of the other four decision variables.

- **Time in position**: TIP stood out as the most dominant factor in survivability. Staying in a position for longer durations increased the chance of victory and lowered the number of casualties suffered. This variable represents the decision the commander faces after taking IDF. The act of displacing leaves the battery vulnerable to IDF while it hurries to get out of the position. Counter battery radar can quickly get the grid for the enemy artillery unit and allow the battery to remain in position and return fire. The results showed an increase in survivability when the battery chose to stay in the position and increase the rate of fire.

- **Emplacement**: Emplacement times did not impact the survivability of units in either employment method. A fast emplacement time solely impacts how fast a unit gets in position and becomes ready to fire. Emplacement impacts lethality and the availability of fire support more than the survivability of artillery units.

- **Displacement**: Howitzer displacement time has a small but measurable impact on survivability. If the unit's goal is to solely focus on minimizing the casualties taken, then displacement time is important. This study did not measure the sole impact of displacement time on survivability due to the time limitations of the researcher. Displacement is discussed in depth in the recommendations for further research section.

2. Recommendations

- **Review the current Table of Organization and Equipment (TO&E) for an artillery battery**: The simulation did not account for personnel and equipment because of the limitations of MANA. As such, the simulation did not test whether distributed operations are feasible with the current TO&E for an artillery battery. Studies show that distributed operations require more support personnel and equipment (NRAC, 2006). Evaluating the current TO&E for distributed operations requires field testing to identify shortfalls.

- **Doctrine review**: Review current artillery doctrine to ensure it includes DFCS. Change formal TTPs and SOPs to reflect the capabilities of DFCS.

- **Add distributed operations to section chief's course**: The responsibilities of the howitzer section chief significantly increase in distributed operations. As a result, section chief training needs to incorporate the additional challenges of distributed operations as to increase the knowledge and proficiency of individual section chiefs.

- **Conduct field testing**: Evaluate the strengths and weaknesses of each employment option with an extensive set of field tests. Since the ability to mass fires is an argument for battery employment and also an argument against distributed operations, test this assumption in the field.

C. MODELING SHORTFALLS

1. Counter Battery Radar

MANA's radar does not function like counter battery radar. The radar agent in MANA can sense any agent on the map at any time. The user scopes the radar's capabilities by defining how and what it is searching for. The researcher programmed a work around through trigger states to limit when the radar picked up artillery units so neither side gained an advantage from the radar. The radar picked up artillery agents after emplacement. A communications delay between the radar and either the FDC or headquarters element modeled the real-world transmission of counter battery data to the howitzers. The radar configuration provided the researcher a suitable way to model the counter battery kill chain.

2. Distributed Howitzer Movement

MANA does not have a function to limit when a distributed howitzer section displaced based on the status of the other sections. The movement of distributed howitzers is based solely on whether that howitzer takes enemy IDF. As a result, there are instances when all six distributed howitzers are moving and unable to fire.

3. Mass Fires

MANA does not have a function to force units to mass fires against a single target. Users can force agents to fire on specific targets based on class and threat level or the target's overall threat level. However, in the distributed scenario the researcher cannot force the Red artillery to mass on a single Blue howitzer consistently. There are some cases where Red does mass fire, but it happens at random. The inability to mass Red howitzer fires results in more movement for the Blue distributed howitzers. This makes the model less effective for a distributed employment since the distributed howitzers are less likely to mass fires because of the frequent movement.

4. Large-scale Combat Scenario

Additional agents slowed the simulation. As a result, the researcher scaled down a combat scenario to only include infantry, artillery, radar, observers, and FDC agents. Scaling the experiment allowed the researcher to focus on the interaction between artillery agents to keep the experiment run time manageable. The analysis excluded all non-artillery casualty numbers and gained enough insight to answer the research question.

5. Estimated Casualty Radius (ECR)

MANA uses a Range/Hit Rate Table to model high explosive weapons. The agent always hits the intended target. Any agents within the specified range to the center of the blast are evaluated based on the value in the Hit Rate Table. Actual values for projectile ECRs are classified and difficult to get. The researcher defined the Range/Hit Rate Table using personal experience, any available opens source data, and subject matter expert advice. Both forces used the same values to keep one side from gaining an advantage from the ECR.

6. Time Step Limit

The simulation stopped at 75,000-time steps if the run did not meet the stopping condition. The simulation reached the maximum number of times steps because either Red destroyed the Blue artillery or forces remained on both sides. During the debugging process the researcher observed a small proportion of simulations reaching the time step maximum with forces remaining. Increasing the time step maximum did not fix the issue. As a result, those runs were labeled a loss for the Blue force since it did not reach the stopping condition. This was only applied to a substantially small number of runs that did not have an impact on the simulation results.

D. MULTIPLE SCENARIOS REQUIRED FOR THOROUGH ANALYSIS

This study focused on distributed operations in a defensive scenario. Distributed operations work best when decentralized howitzers can exploit the advantages provided by situation and terrain. Further analysis for other types of scenarios are required to analyze the full impact of the distributed employment tactic. Recommended situations for further analysis are provided below:

- Offensive scenario: Artillery units in offensive scenarios act differently than in defensive ones. Infantry movements force the supporting artillery unit to move forward as required to engage targets in the AO. The impact of distributed operations on survivability in a counter battery threat environment should also be evaluated.

- Large-scale combat: The simulation did not include long-range artillery assets or aviation. A large-scale combat scenario should be built to test the survivability of distributed operations under threat of long-range artillery and aviation assets.

- Different types of operating environments: The simulation used a location that included open farmland and a forested environment used by the defense. Distributed operations should be evaluated in the various types of environments that the Marine Corps operates in.

E. FOLLOW ON RESEARCH

1. Exploration of the Dominant Decision Variable

Time constraints kept the researcher from further research into the impact of the four non-dominant decision variables. The researcher recommends further experiments to hold the TIP constant and vary the other four decision variables to gain insight into the significance of each variable. Decision makers use those decision variables in acquisition decisions and should know the full impact of each one on survivability.

2. Different Types of Ammunition

The study used the standard M795 High Explosive projectile to model the range and effects of the artillery systems. Further research is recommended for distributed operations with different types of ammunitions like Excalibur and DPICM.

3. Unmanned Aerial Systems

Further research into the impact of unmanned aerial systems on the employment of artillery can help gain insight into future TTPs.

F. FINAL THOUGHTS

This research intends to put data behind an idea. The researcher first encountered distributed operations in 2016 while at 1st Battalion, 10th Marine Regiment. Battery C executed a proof of concept for distributed operations to test digital communications and the transmission of firing data over large distances. Even after the success of the field exercise, distributed operations fell on the back burner. Nay-sayers succeeded in keeping the community stagnant even at the cost of preparing for the next big fight. This research serves as a call to arms for the younger generation of artillerymen in the community to support change with data. Ideas backed by data will support the modernization of the artillery community.

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LIST OF REFERENCES

Burgess, R. B. (2010). *A radar for all missions.* Northrup Grumman. https://www.northropgrumman.com/Capabilities/GATOR/Documents/gator_seapower.pdf

Browne, K. (2018). *Self-propelled wheeled howitzer for Marine Corps use: capability-based assessment*. [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/61319

Crane, B. (1999). The M777: Marine artillery's jackpot. Marine Corps Gazette, 83(7), 26–30. Retrieved from http://search.proquest.com/docview/221418131/

Fox, A. C. (2017). *The Russian-Ukrainian war: Understanding the dust clouds on the battlefield*. Modern War Institute at West Point. https://mwi.usma.edu/russian-ukrainian-war-understanding-dust-clouds-battlefield/

Goldman, H. I. (2007). *Towed artillery digitization.* NDIA Storage. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2007/armaments/Goldman.pdf

Gordon IV, J., Matsumura, J., Atler, A., Boston, S., Boyer, M., Lander, N., Nichols, T. (2015). *Comparing U.S. Army systems with foreign counterparts* (Report No. RAN126499).https://www.rand.org/content/dam/rand/pubs/research_reports/RR700/RR716/RAND_RR716.pdf

Gourley, S. R. (2014). *PM towed artillery systems.* Defense Media Network. https://www.defensemedianetwork.com/stories/pm-towed-artillery-systems/

Grau, L. W., & Bartles, C. K. (2016). *The Russian way of war: Force structure, tactics, and modernization of the Russian ground forces*. Army University Press. https://www.armyupress.army.mil/Portals/7/Hot%20Spots/Documents/Russia/2017-07-The-Russian-Way-of-War-Grau-Bartles.pdf

Jane's. (2017). *Karabin Maszynowy (PKM series) 7.62 mm general-purpose machinegun.* https://janes.ihs.com/Janes/Display/JIW_0653-JIW_

Jane's. (2018). *ZOOPARK-1M.* https://janes.ihs.com/Janes/Display/jrew0218-jc4il

Jane's. (2019a). 2S19 *Msta-S.* https://janes.ihs.com/Janes/Display/JAA_0442-JAAD

Jane's. (2019b). *AK-47 7.62 x 39mm assault rifle.* https://janes.ihs.com/Janes/Display/JIW_0423-JIW_

Jane's. (2019c). *M4 5.56 mm carbine.* https://janes.ihs.com/Janes/Display/jiw_9392-jiw_

Jane’s. (2019d). *M777 155mm.* https://janes.ihs.com/Janes/Display/JAA_0550-JAAD

Jane’s. (2020a). *AN/TPS-80 ground/air task-oriented radar*. https://janes.ihs.com/Janes/Display/jrewa264-jc4il

Jane’s. (2020b). *FN MAG 58 7.62 x 51mm general-purpose machinegun.* https://janes.ihs.com/Janes/Display/JIW_0613-JIW_

Kane, K. (2017). Adapting towed artillery today to meet a near-peer competitor tomorrow. *Fires, PB 644–17-5*, 26–29. https://sill-www.army.mil/firesbulletin/archives/2017/sep-oct/sep-oct.pdf

Hernandez, A., Lucas, T., & Carlyle, M. (2012). Constructing nearly orthogonal Latin hypercubes for any nonsaturated run-variable combination. *ACM-Transactions on Modeling and Computer Simulation, 22(4), pp.20:1-20:17.* https://calhoun.nps.edu/handle/10945/38211

McIntosh, G. C., Galligan, D. P., Anderson, M. A., & Lauren, M. K. (2007). *MANA (map aware non-uniform automata) version 4 user manual*. DTA Technical Note 2007/3. Defense Technology Agency.

Michel, C. (2006). *Evaluating the Marine Corps’ artillery triad in STOM operations* [Master’s thesis, Naval Postgraduate School]. NPS Restricted Archive.

Moffat, J., Smith, J., & Witty, S. (2006). Emergent behaviour: Theory and experimentation using the MANA model. *Journal of Applied Mathematics and Decision Sciences*, 2006(5), *13*. https://doi.org/10.1155/JAMDS/2006/54846

Shim, Y. (2017). *An analysis of “shoot-and-scoot” tactics*. [Master’s thesis, Naval Postgraduate School]. NPS Archive: Calhoun. http://hdl.handle.net/10945/53047

Szoldra, P., (2019). *The Marines are training to fight big wars again*. Task and Purpose. https://taskandpurpose.com/corps-great-power-competition

United States Marine Corps (1996). *Tactics, techniques, and procedures for the field artillery cannon battery* (MCWP 3-1.6.23). https://usacac.army.mil/sites/default/files/misc/doctrine/CDG/cdg_resources/manuals/fm/fm6_50.pdf

United States Marine Corps (1998). *Expeditionary Operations* (MCDP 3). https://www.marines.mil/portals/1/Publications/MCDP%203%20Expeditionary%20Operations.pdf?ver=2012-10-11-164103-873

United States Marine Corps (2011*). Marine Corps artillery safety standing operating procedures* (JRegtO P3570.1D Ch 2). https://sill www.army.mil/usmc/documents/fire_support.pdf

United States Marine Corps (2015). *Artillery training and readiness manual* (NAVMC 3500.7B).https://www.marines.mil/Portals/59/Publications/NAVMC%203500.7B%20W%20CH%201-2.pdf?ver=2017-02-17-104111-323

United States Marine Corps (2016a). *Artillery operations* (MCTP 3-10E). https://www.marines.mil/Portals/59/Publications/MCTP%203-10E%20Formerly%20MCWP%203-16.1.pdf?ver=2017-10-31-102101-010

United States Marine Corps (2016b). *Tactics, techniques, and procedures for the field artillery manual cannon gunnery* (MCRP-3.10E.4). https://www.marines.mil/Portals/59/Publications/MCRP%203-10E.4%20Formerly%20MCWP%203-16.4.pdf?ver=2017-09-26-101122-060

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