2010-06

# Supporting Marine Corps Enhanced Company Operations : a quantitative analysis

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# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# THESIS

**SUPPORTING MARINE CORPS ENHANCED COMPANY OPERATIONS: A QUANTITATIVE ANALYSIS**

by

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June 2010

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| REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188* |
|---|---|



| **1. AGENCY USE ONLY *(Leave blank)*** | **2. REPORT DATE** June 2010 | **3. REPORT TYPE AND DATES COVERED** Master's Thesis |
|---|---|---|

**4. TITLE AND SUBTITLE** Supporting Marine Corps Enhanced Company Operations: A Quantitative Analysis

**5. FUNDING NUMBERS**

**6. AUTHOR(S)** Daniel S. Hinkson

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Postgraduate School
Monterey, CA 93943-5000

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
N/A

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES** The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ___________N/A_________________.

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited

**12b. DISTRIBUTION CODE**
A

**13. ABSTRACT (maximum 200 words)**

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**14. SUBJECT TERMS**
Enhanced Company Operations, ECO, Distributed Operations, DO, Enhanced MAGTF Operations, EMO, MANA, Seabasing, Marine, Logistics, Agent-Based Model, Data Farming, Simulation, Design of Experiments

**15. NUMBER OF PAGES**
113

**16. PRICE CODE**

| **17. SECURITY CLASSIFICATION OF REPORT** | **18. SECURITY CLASSIFICATION OF THIS PAGE** | **19. SECURITY CLASSIFICATION OF ABSTRACT** | **20. LIMITATION OF ABSTRACT** |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UU |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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# SUPPORTING MARINE CORPS ENHANCED COMPANY OPERATIONS: A QUANTITATIVE ANALYSIS

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN OPERATIONS RESEARCH**

from the

**NAVAL POSTGRADUATE SCHOOL**
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# ABSTRACT

This research explores the capability requirements for the employment of a Marine Rifle Company organized to conduct Enhanced Company Operations (ECO). It uses a simulation model, built in an agent-based simulation tool called MANA, to evaluate the logistical impact of ECO on a Marine Expeditionary Unit (MEU). ECO involves reorganizing and augmenting the traditional rifle company in a manner that contributes to "enhanced" command and control, intelligence, logistics, and fires capabilities. The end state is to develop the company's ability to become the base maneuver element of the Marine Air Ground Task Force, a role traditionally held by the infantry battalion. This research used a robust design of experiments method called the Nearly Orthogonal Latin Hypercube to vary a set of design factors in an efficient manner, culminating in over 5,460 simulated missions. Statistical results indicate that it is possible to support an enhanced company with current MEU assets, and that resupply responsiveness is more important than the unit's distance to the seabase. This research also confirms the validity of investing in the MV-22, due to the increased capabilities it brings to the MEU commander.

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## THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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# LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

| | |
|---|---|
| 1STSGT | First Sergeant |
| ABD | Agent Based Distillations |
| ABM | Agent-Based Model |
| A/C | Aircraft |
| AO | Area of Operations |
| AOR | Areas of Responsibility |
| BAF | Bunduri Armed Forces |
| BLT 1/1 | Battalion Landing Team 1st Battalion, 1st Marine Regiment |
| CA | Cellular Automaton |
| $C^2$ | Command and Control |
| Cal | Caliber |
| CLIC | Company-level Intelligence Cell |
| CLOC | Company-level Operations Center |
| Co | Company |
| CoLT | Company Landing Team |
| CAS | Complex Adaptive Systems |
| CSV | Comma-separated Value |
| DO | Distributed Operations |
| DODIC | Department of Defense Identification Code |
| DOE | Design of Experiment |
| DOS | Day(s) of Supply |
| ECO | Enhanced Company Operations |
| EFSS | Expeditionary Fire Support System |
| EMO | Enhanced MAGTF Operations |
| FARP | Forward Arming and Refueling Point |
| FMFM | Fleet Marine Force Manual |
| FST | Fire Support Team |
| Ft | Foot or Feet |
| GW | Gross Weight |
| GYSGT | Gunnery Sergeant |

| | |
|---|---|
| HE | Heavy Equipment |
| HQ | Headquarters |
| Hr | Hour |
| IED | Improvised Explosive Device |
| Illum | Illumination |
| ISR | Intelligence, Surveillance, Reconnaissance |
| ITV | Internally Transportable Vehicle |
| JTAC | Joint Terminal Air Controller |
| km | Kilometers |
| kph | Kilometer(s) per Hour |
| LAV | Light Armored Vehicle |
| Lbs/lbs | Pound(s) |
| LOE | Limited Objective Experiment |
| MAGTF | Marine Air Ground Task Force |
| MANA | Map-Aware Non-uniform Automata |
| MCO | Marine Corps Order |
| MCWL | Marine Corps Warfighting Laboratory |
| MDC | Movement for Democratic Change |
| min | Minimum |
| MEU | Marine Expeditionary Unit |
| MLG | Marine Logistics Group |
| mm | Millimeter |
| MOS | Military Occupational Specialty |
| MOE | Measure of Effectiveness |
| MPF | Manicaland Peoples Force |
| NCO | Non-commissioned Officer |
| nm | Nautical Miles |
| NOLH | Nearly Orthogonal Latin Hypercube |
| NPS | Naval Postgraduate School |
| OAD | Operations Analysis Division |
| OIF | Operation Iraqi Freedom |
| OMFTS | Operational Maneuver from the Sea |

| | |
|---|---|
| Plt | Platoon |
| RO | Radio Operator |
| SA | Situational Awareness |
| SAW | Squad Automatic Weapon |
| sec | Second |
| SEED | Simulation Experiments and Efficient Designs |
| Sqd | Squad |
| Sqft | Square Foot/Feet |
| Std Dev | Standard Deviation |
| Std Err Mean | Standard Error Mean |
| TAMCN | Table of Authorized Material Control Number |
| T/O | Table of Organization |
| T/E | Table of Equipment |
| UAS | Unmanned Aerial Systems |
| USA | United States Army |
| USMC | United States Marine Corps |
| VTOL | Vertical Take Off and Landing |
| XML | eXtensible Markup Language |
| XO | eXecutive Officer |

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# EXECUTIVE SUMMARY

The modern irregular warfare environment has dramatically impacted the battle space assignments and mission scope of tactical units that now take on much more responsibility than traditionally called for. The purpose of this research is to gain insights into the required capabilities, tactics, and the associated support effort of the enhanced company operating on the noncontiguous battlefield. It identifies some of the risks and planning considerations that a Marine Expeditionary Unit (MEU) commander might consider in the decision-making process.

This research utilizes an agent-based simulation tool, Map-Aware Non-uniform Automata (MANA), developed by the New Zealand Defence Forces, to evaluate the logistical impact that Marine Corps Enhanced Company Operations (ECO) could have on a MEU. This summary gives a broad overview of ECO, describes an approved modeling scenario, the research methodology, and the analytical results. This research is intended to assist the development of ECO concepts, techniques, tactics, and procedures as this cutting-edge doctrine develops and matures. Specifically, this thesis addresses the following questions:

- Given the current organizational structure of a MEU, what is the logistical impact of supporting an enhanced company with the MEU's supporting assets?
- What are the critical logistical factors relating to mission success during ECO within the context of a given scenario?
- What are the critical logistical capabilities of the MEU that will enable it to provide continuous sustainment to an enhanced company?
- What is the logistical impact of increasing the distance of the supported unit from the seabase?

These questions guided this research in the application of modern simulation, modeling techniques, and data analysis to focus on the logistical requirements of an enhanced company.

The Marine Corps Warfighting Laboratory (MCWL) is currently exploring the viability of ECO. This research is in direct support of their effort to enhance the fighting capability and reach of the Marine Air Ground Task Force (MAGTF).

ECO requires reorganizing and augmenting the traditional rifle company in a manner that contributes to "enhanced" command and control, intelligence, logistics, and fires capabilities. This process not only involves personnel changes, but also specific training and technological improvements. The end state is to develop the company's ability to become the base maneuver element of the MAGTF, a role traditionally held by the infantry battalion.

This research is centered on a realistic Africa-based scenario, provided by MCWL, which allows enemy agents to influence the logistical demand of the supported company. A distillation of this scenario, incorporated into MANA, models the interactions between the Marine enhanced company and insurgent forces in the simulated ECO environment. These interactions provide insights into the effectiveness of the MEU's resupply capability.

Design of experiment (DOE) principles guided the execution of two simulation-based experiments, which ensured a comprehensive exploration of the problem space and efficient use of simulation resources. A robust DOE method, called the Nearly Orthogonal Latin Hypercube (NOLH), is incorporated to achieve a comprehensive statistical analysis. This research also uses an analytical technique, known as Data Farming, which entails running a model many times while systematically changing input parameters according to the DOE. The data sets resulting from these experiments are then explored statistically to see what patterns and other behaviors emerge.

The NOLH design determined how the design factors were varied over 5,460 simulation runs, resulting in analyzable data capable of providing valuable insight into the questions above. The analytical results of this exploration will help focus planners at MCWL on key parameters as they design future ECO experiments and develop ECO doctrinal concepts. Specific findings, based on the assumptions of this scenario and the analyzed output, include:

- It is possible to support an enhanced company with current MEU assets.
- The number of sorties required to support an enhanced company over a two-week period remained relatively stable.
- For maximum effectiveness, allocation of one aircraft per platoon position is required.
- Distance from the company position to the seabase matters, but not as much as response time to rapid requests. Logistical planners should work to minimize response time by taking steps such as building prepackaged supply bundles in anticipation of requests.
- In a rapid request scenario, an MV-22's speed significantly increases the MEU's responsiveness over using CH-53s.
- If all other parameters are equal, using MV-22s enable a seabase to be further away from the supported unit than using CH-53s.
- The combat intensity increases the demand on the MEU's assets, so reserve capacity is essential.
- This research validates the MV-22's contribution to the viability of the seabase concept.

The MANA model developed for this research can be adapted to explore many other questions. For example, it could be used to evaluate a scheduled resupply model, which could reveal that the CH-53's cargo capacity advantages trump the VM-22's speed advantage under that circumstance. This model could also be adapted to explore other aircraft options, like cargo unmanned aerial systems or C-130 air delivery capabilities.

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# ACKNOWLEDGMENTS

This thesis has my name on it, but it has truly been a team effort. First, I would like to thank my wife, Meghan, for her continuous support and encouragement. As always, I could never be as successful as I am without her.

Next, I would like to thank the SEED Center Team. This includes my adviser, Dr. Tom Lucas, as well as Research Associate Mary McDonald, Colonel Ed Lesnowicz, USMC (Ret.), and Drs. Paul and Susan Sanchez. Special mention goes to Mary, who spent countless hours with me deriving workable algorithms and troubling shooting pesky software. I sincerely appreciated the unified support the SEED Center gives its thesis students.

There are a few others that helped make this thesis possible: at the Marine Corps Warfighting Lab, Colonel Vince Goulding, USMC (Ret.), was always responsive to my incessant questions. Mr. Mark Anderson, with New Zealand's Defence Technology Agency, saved the day when he provided a new version of MANA to specifically address the needs of this thesis. My second reader, Mr. Jim Evans, who provided the "outsider-looking-in" perspective every thesis needs. Mr. Richard McCourt and Capt Kyungtack Oh, ROK Army, both provided a week's worth of assistance at the International Data Farming Workshop 20. My parents, who we were fortunate to be near these past two years, also provided support and encouragement. Thank you all for your contributions to this work.

Lastly, I must recognize the hand of my Heavenly Father. He allowed me to overcome significant challenges—including back surgery—over the past few months. His hand has guided me, a former high school dropout, to this pinnacle in my educational career, for which I am humbly grateful.

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# I. INTRODUCTION

> Battles are won by slaughter and manoeuver. The greater the general, the more he contributes in manoeuver, the less he demands in slaughter.
>
> —Winston Churchill (Headquarters, USMC, 1997, p. 21)

## A. OVERVIEW

The United States Marine Corps (USMC) uses maneuver warfare as a basic doctrinal concept to fight its battles. Maneuver warfare demands the ability to avoid the enemy's strengths and attack his weaknesses in ways that are advantageous to the overall strategy. This overarching concept has heavily influenced the development of the Marine Air Ground Task Force (MAGTF)—size-scalable, combined-arms, multi-mission-capable force used across the spectrum of conflict. The Marine Corps is continually developing tactics, techniques, procedures, and technologies that seek to increase the efficiency and lethality of the MAGTF. In this spirit, the Marine Corps Warfighting Laboratory (MCWL), whose "purpose is to improve current and future naval expeditionary warfare capabilities" (Marine Corps Warfighting Laboratory homepage, 2010), is currently exploring the viability of a concept called Enhanced Company Operations (ECO). This research explores and describes the development of ECO, and analyzes the logistical supportability of an enhanced company operating in an austere and hostile environment, using simulation and modeling techniques.

## B. BACKGROUND AND MOTIVATION

In September 2005, Matthew D. Bain, then a Marine Corps Captain, completed a thesis entitled "Supporting a Marine Corps Distributed Operations Platoon: A Quantitative Analysis." His thesis used simulation modeling and statistical analysis to evaluate the logistical supportability of the distributed operations (DO) concept. DO involved spreading specialized, platoon-sized infantry units across a battlefield in a much more dispersed manner than traditional doctrine allowed. Captain Bain found that the concept was logistically supportable, but it used a large proportion of the supporting unit's aircraft assets, thus substantially limiting the commander's ability to support other priorities.

MCWL conducted a number of experiments from 2004 to 2006 to test DO concepts. In an article in the April 2008 issue of the *Marine Corps Gazette*, Colonel Vincent J. Goulding, Jr., USMC (Ret.), the director of MCWL's Experiments Division, summarized the contribution that DO had made to training, manning, and equipping the Marine infantry platoon (Goulding, 2008b). In 2008, the DO concept evolved to company-sized operations supported by increased intelligence and command and control ($C^2$) capabilities. This evolved concept is called ECO and comes, in part, as a result of current operations in Iraq and Afghanistan. In August 2008, the Commandant of the Marine Corps, General James Conway, signed a white paper entitled, "A Concept for Enhanced Company Operations," which states:

> Enhanced Company Operations describes an approach to the operational art that maximizes the tactical flexibility offered by true decentralized mission accomplishment, consistent with commander's intent and facilitated by improved command and control, intelligence, logistics, and fires capabilities. Enhanced Company Operations will be reliant on increased access to, and organic control of, functional support, as well as excellence at the individual, squad, and platoon levels. As such, it builds on the results of Distributed Operations experimentation and capability development to provide battalion commanders the critical link between operational planning and squad level tactical execution (Conway, 2008, pp. 57-58).

ECO will involve a number of structural, manning, and equipment changes to the Marine Corps' traditional rifle company, as well as changes to how the company is deployed and supported; however, these changes are still evolving. In fact, the Commandant's paper addresses the probable need to enhance the MAGTF in support of the enhanced company. For example, it may be necessary to incorporate cargo unmanned aerial systems (UAS) into the MAGTF to facilitate logistical support to the deployed companies. Not surprisingly, this concept has been entitled Enhanced MAGTF Operations (EMO). In the August 2009 issue of the *Marine Corps Gazette*, Colonel Goulding authored an article on EMO that states:

> EMO is an approach to expeditionary operations that maximizes the flexibility offered by highly capable tactical formations that are commanded and controlled, supported, and sustained by a unitary command element equally capable of providing organic support as it is of leveraging joint and coalition partners. EMO builds on ECO to ensure that improvements at the tactical level are matched by those at the operational level and shared across the MAGTF (Goulding, 2009, p. 14).

As shown, these evolving topics comprise today's cutting edge efforts at improving the MAGTF. This effort will assist that improvement.

## C. RESEARCH QUESTIONS

This research will analyze the logistical supportability of an enhanced company operating in an austere and hostile environment, using methods and analysis similar to what Captain Bain used to evaluate the DO platoon. Specifically, this research addresses the following questions:

- Given the current organizational structure of a Marine Expeditionary Unit (MEU), what is the logistical impact of supporting an enhanced company with the MEU's supporting assets?
- What are the critical logistical factors relating to mission success during ECO within the context of a given scenario?
- What are the critical logistical capabilities of the MEU that will enable it to provide continuous sustainment to an enhanced company?
- What is the logistical impact of increasing the distance of the supported unit from the seabase?

These questions will guide the use of modern simulation, modeling techniques, and data analysis to focus on the logistical requirements of an enhanced company.

## D. BENEFITS OF THE STUDY

This research will inform MCWL's ECO Limited Objective Experiment in the summer of 2010, and further logistics-specific experiments in 2011. It will also influence future experimental objectives, funding, and the development of tactics, techniques, and procedures relating to ECO and EMO. The model and associated data developed for this research is available to facilitate related quick-turn studies. Another quote from the Commandant's white paper reinforces the need for this analysis:

> Logistics has the potential to be the Achilles' heel of the company's ability to conduct the types of expeditionary and irregular warfare our warfighting concepts envision. Traditional and time-honored approaches need to be reviewed in the context of distributed operations in austere environments. Fast moving or dismounted tactical units will need to be secure in the knowledge that tailored re-supply will occur when they need it, with only what they need, exactly where they need it (Conway, 2008, p. 60).

## E. METHODOLOGY

To explore this problem, this research uses a specific scenario to set up the initial battlefield parameters. An agent-based simulation tool developed by the New Zealand defense forces, called Map-Aware Non-uniform Automata (MANA), will use these factors to model the interactions between blue (friendly) and red (enemy) forces in a simulated ECO environment. Design of experiment (DOE) principles will guide execution of the simulation-based experiments, which ensures a comprehensive exploration of the problem space and efficient use of simulation resources. The DOE will dictate how analysis factors are varied over multiple simulation runs, resulting in analyzable data capable of providing valuable insight into the research questions. The analytical results of this exploration will help focus planners at MCWL on key parameters as they design future ECO experiments and develop ECO doctrinal concepts.

The remainder of this research will flow as follows. Chapter II describes ECO in more detail and outlines the modeling scenario. Chapter III describes the MANA model, explains the simulation parameters, the DOE, and measures of effectiveness (MOEs). Chapter IV describes the data analysis results and findings, and Chapter V summarizes these results.

# II. MODEL DEVELOPMENT

> Conventional wisdom tells us that the battalion is the smallest tactical formation capable of sustained independent operations; current operations tell us it is the company.
>
> —General James T. Conway, USMC (Conway, 2008)

## A. INTRODUCTION

This chapter discusses the background and development of ECO. It also outlines an enhanced company's organizational structure, equipment, and capabilities. Section D of this chapter describes the modeling scenario and modeling tools that this research uses.

Since the attacks on September 11, 2001, the United States has been engaged in what has been termed "The Long War." This title reflects the reality of an intergenerational struggle against extremist ideas, and those who choose to back them with force and violence. Future battles in The Long War will be defined by confronting asymmetrical threats and nonstate actors. These changes from traditional conflicts between state actors have forced the Marine Corps to develop new doctrinal strategies to confront the new reality. For example, Fleet Marine Force Manual 6-4 (1978), the Marine Corps' doctrinal publication for rifle company/platoon operations, states that a rifle company's defensive battle area should be 1,100 meters deep with a frontage of 1,500 meters, in ideal terrain conditions. In current operations, rifle companies are responsible for areas many times that size (V. J. Goulding, personal communication, March 11, 2010). Tactics and technology have progressed to the point that modern operations are much more dispersed, and $C^2$ is much more decentralized. The Marine Corps Vision and Strategy 2025 (2008) document states, "For the Corps, we must continue to prepare for the challenges that loom on the horizon. We are by law, and will continue to be, the Nation's force in readiness—'most ready when the Nation is least ready'" (p. 13). Chapter 5 of that document outlines the implications to the Marine Corps' force structure as it moves further into the twenty-first century. As a direct result of these and other realities, ECO has emerged as a stepping stone to that future state.

## B. WHAT ARE ENHANCED COMPANY OPERATIONS (ECO)?

### 1. Overview

ECO involves reorganizing and augmenting the traditional rifle company in a manner that contributes to "enhanced" $C^2$, intelligence, logistics, and fires capabilities. This process not only involves personnel changes, but also specific training and technological improvements. The end state is an improved ability for the company to become the base maneuver element of the MAGTF, a role traditionally held by the infantry battalion. Changes include the incorporation of a company-level operations center (CLOC), a company-level intelligence capability, enhanced fire support coordination, and personnel specifically tasked to focus on logistics (Goulding, 2009a). To date, the personnel changes have not required additional numbers, but only a change to military occupational specialty (MOS) mixes and structuring within the company. These changes provide the company commander with the means to effectively coordinate the battlefield functions throughout his area of operations (AO). Specific changes are discussed in Section B.3.

### 2. Concept Development

The first considered enhancement to the standard rifle company was the company-level intelligence cell (CLIC). During the I Marine Expeditionary Force's Irregular Warfare Conference in June 2007, the conference working groups identified a company-level intelligence capability as an emerging requirement. Because maneuver warfare is dependent on intelligence-driven operations, company commanders in Operation Iraqi Freedom (OIF) were already creating this capability from within their existing personnel structure. The MCWL conference participants used the CLIC concept as an opportunity to shift from the platoon-focused DO program to the current company-focused effort. Colonel Goulding stated, "For all intents and purposes, enhanced company operations, or ECO, was born" (Goulding, 2008b, p. 18). MCWL conducted two limited objective experiments (LOEs), identified simply as LOEs 1 and 2, to begin exploring the CLIC concept soon after the conference (Goulding, 2008b).

As the LOEs for the CLIC progressed, and current operations in OIF and Afghanistan were studied, MCWL and the other organizations involved decided to expand the CLIC into a CLOC. The demands of current battlefields require that more battlefield functions, like fire support coordination and logistics, be pushed to the company level. The CLOC became the "centerpiece" of LOE 2. The LOE process included a research phase to define required tasks, development of a prototype "best practices" model, manning and equipping that model, conducting the required training, and then running the test unit through exercise MOJAVE VIPER, conducted at Twentynine Palms, California during the summer of 2009 (Goulding, 2008b). Other experiments conducted include LOE 3, which looked at unmanned air and ground vehicles to support distributed logistics and casualty handling. The CLOC concept also evolved to the CLOC (light). At its essence, this means that everything a CLOC needs must be transportable by the MV-22 Osprey (Goulding, 2009b). During the CLOC (light) LOE, a prototypical communications suite was used to exercise $C^2$. Additionally, the 10th Marines conducted a distributed artillery experiment at Fort Sill, Oklahoma using the M777 howitzer (Goulding, 2009b).

As the ECO organizational capability requirements continue to define themselves, so too do the mission requirements. The first MCWL LOEs considered forward-operating-base-centered experiments because the units conducting them did so as part of their predeployment training for current operations. The next experiment, however, will get back to more traditional Marine Corps expeditionary concepts. In concert with the seabasing and ship-to-objective maneuver concepts, LOE 4, to be held in July 2010, will test the company landing team (CoLT). A traditional battalion landing team is centered around an infantry battalion, reinforced with other MAGTF elements, depending on mission requirements. The CoLT is a scaled down, but similarly task-organized unit (Goulding, 2009b). This concept will give the MAGTF the higher degree of flexibility demanded by today's operational environment. Understandably, the CoLT will require table of organization (T/O) changes, which are discussed in the next section. LOE 4 will exercise the CoLT.

When taken together, the CLIC, the CLOC, and the CoLT form the core of the ECO concept as it currently stands.  Pushing these capabilities to the company level is a tremendous paradigm shift from traditional operations, yet has great potential to increase the lethality of the MAGTF.  As the concepts change, so must the organization and equipment if these concepts are going to be realized.

### 3. Organization

The current Marine Corps rifle company T/O 1013G requires 182 Marines and includes a headquarters section, three rifle platoons, and a weapons platoon, which includes a 60mm mortar section, a machine gun section, and an assault section (see Figure 1).

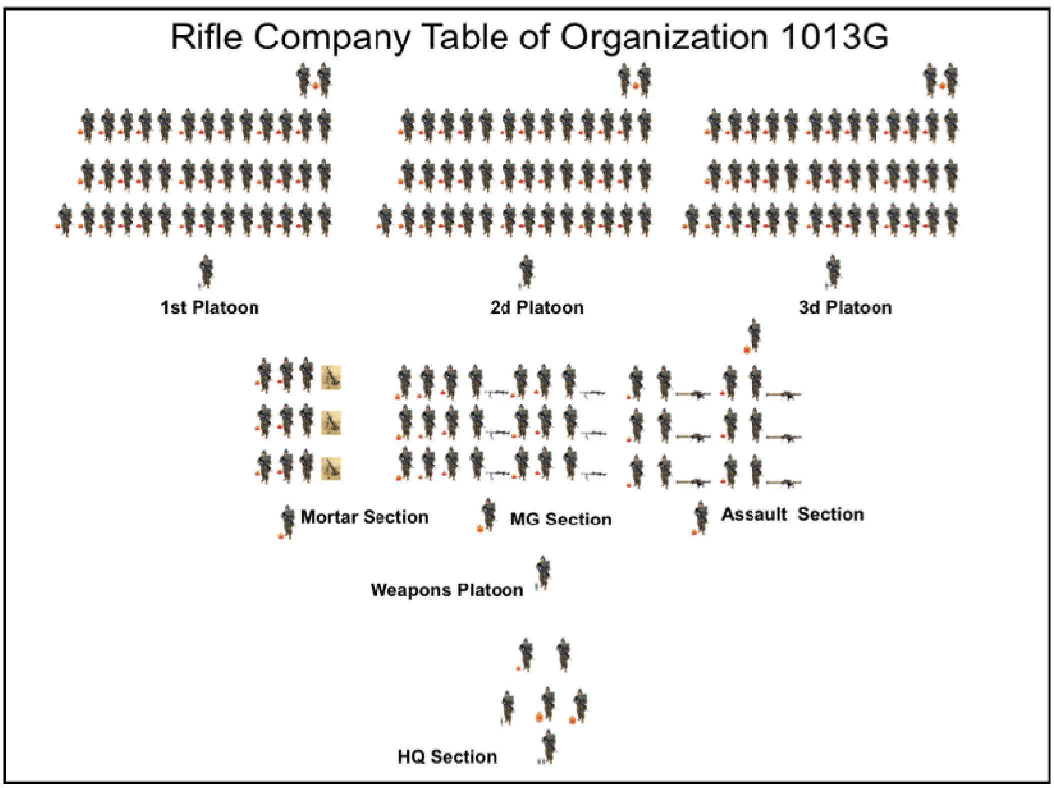



Figure 1. Current Marine Corps Rifle Company Table of Organization 1013G (From: Infantry Officer's Advisory Group Enhanced Company Operations Update PowerPoint Brief, 2009).

The major changes to the experimental enhanced company T/O X4.4 include doubling the headquarters section with Marines to run the CLOC, reducing the number of Marines in each rifle platoon from 43 to 42, moving the assault section Marines into the rifle platoons, and including an 11-Marine scout section (with joint fires observer) in the weapons platoon. These structural changes keep the number of Marines at 182 (see Figures 2 and 3) (Goulding, 2009b).

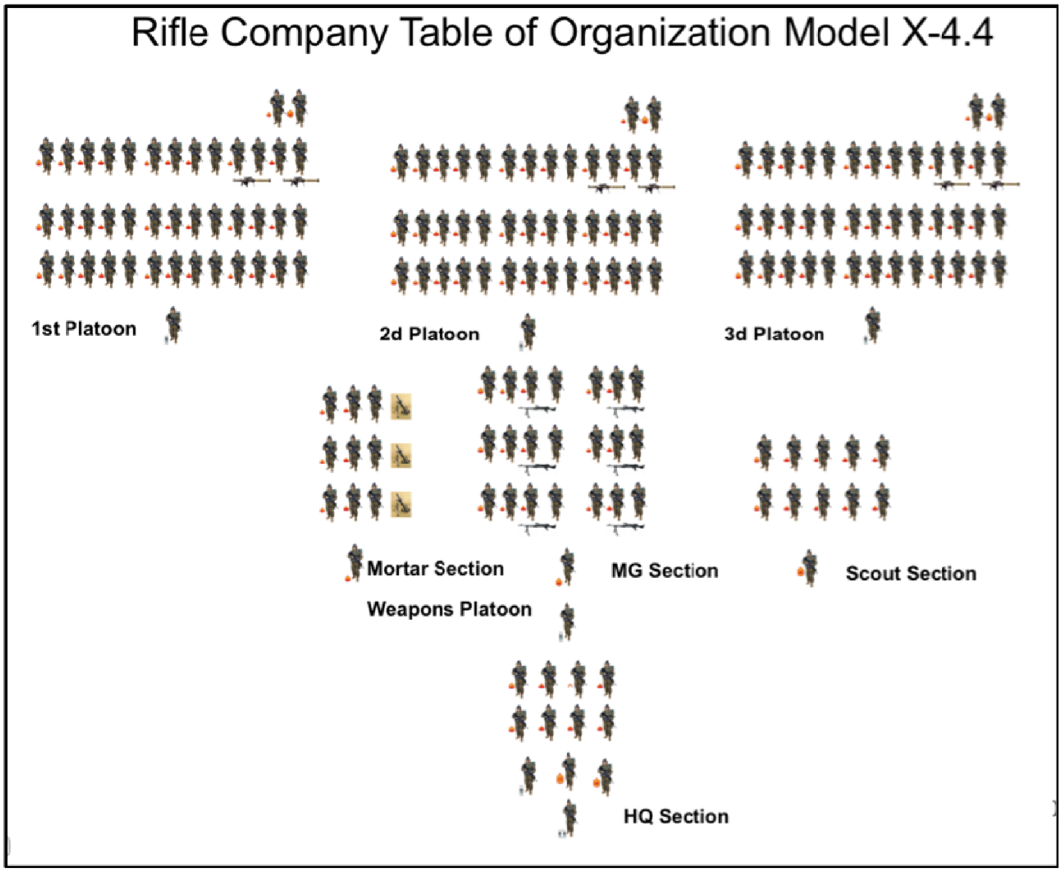



Figure 2. Experimental Marine Corps Enhanced Rifle Company Table of Organization Model X-4.4 (From: Infantry Officer's Advisory Group Enhanced Company Operations Update PowerPoint Brief, 2009).

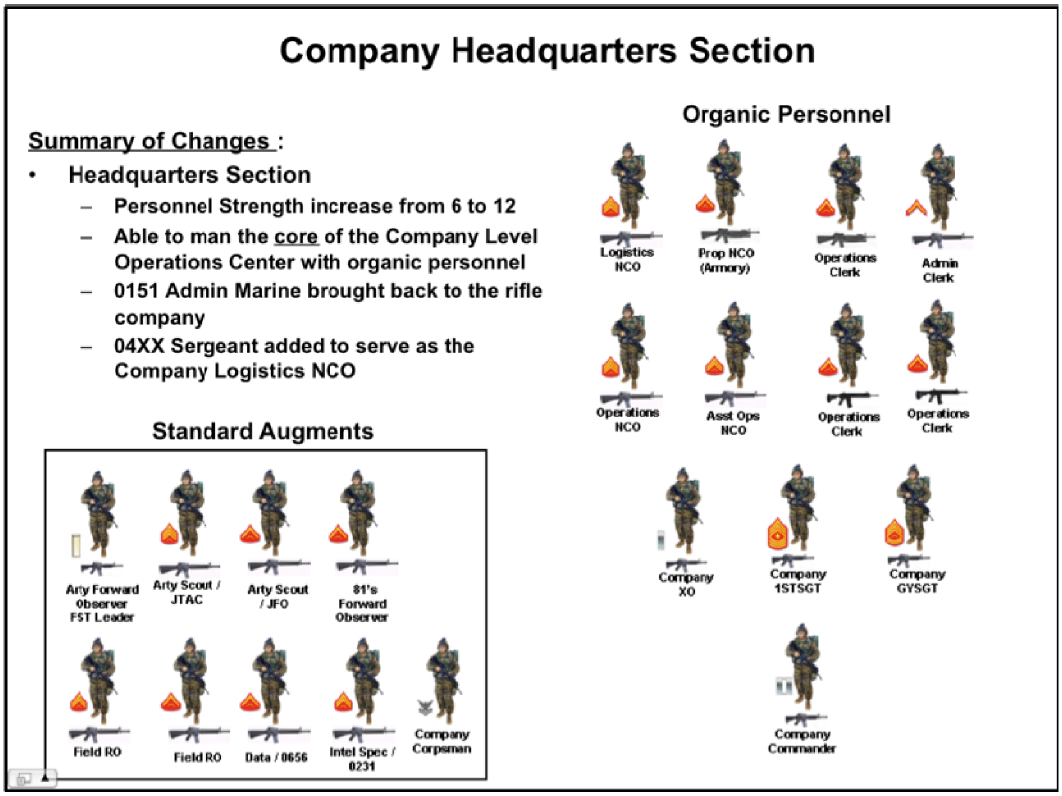



Figure 3. Experimental Marine Corps Enhanced Rifle Company Headquarters Section and Standard Augments (From: Infantry Officer's Advisory Group Enhanced Company Operations Update, 2009).

#### 4. Equipment

The initial equipment baseline for the enhanced table of equipment (T/E) is the same as the traditional T/E. As experimentation continues, technology evolves, requirements are identified, and systems are acquired, the T/E will change to support the mission requirements. For example, to support $C^2$ functions, an over-the-horizon/on-the-move tactical radio is necessary, but a specific system has not yet been identified to fulfill this requirement, although there are candidates. In addition to the radio, when one considers the range of ECO capabilities that need to be supported, the equipment requirements are quite large and may include:

- Data systems
- Intelligence, Surveillance, Reconnaissance (ISR) sensors
- UASs

- Unmanned Ground Vehicles
- Targeting devices
- Improved company-level organic fires capability
- Water production
- Power production

All of these considerations need to be taken under the context that there are firm weight and space constraints. For, as S. L. A. Marshall wrote in *The Soldier's Load and the Mobility of a Nation* (2004), "No logistical system is sound unless its first principle is enlightened conservation of the power of the individual fighter" (p. iii). This thesis considers current and near future equipment sets in order to keep the simulations close to what is presently realistic.

#### 5. Additional Capabilities

Other changes will need to be made in addition to manpower and equipment changes. Perhaps first among these is training. The current pipeline that produces infantry company commanders and their staff does not adequately prepare them for enhanced operations. Additionally, the training that produces infantryman will need to be examined if ECO is to become a reality. There are advances in training simulation technologies that will perhaps complement formal schooling and live training. These technologies should be leveraged if ECO is to become reality. It has also become evident that the MAGTF support structure will need enhancements to support ECO (Goulding, 2009a). The demands on the MAGTF's $C^2$, communications, fires, and logistics will all increase to support ECO, especially in a ship-to-objective maneuver context.

### C. SCENARIO DESCRIPTION

#### 1. Overview

This study uses a scenario developed by MCWL and used during the ECO Fires Conference of April 21-23, 2009, which provides a realistic operational environment in which to test the ECO concept. The fictional scenario takes place on the African continent in the border area between Burundi and the Democratic Republic of the Congo.

In the notional orders describing the scenario, MCWL changed the names of the countries to prevent others from mistaking them for real-world orders. Additionally, the border between Burundi and Tanzania is notionally considered coastline. In other words, Tanzania is covered by the Indian Ocean, as shown in Figure 4. From this point forward, Burundi is referred to as Bunduri, and the Democratic Republic of the Congo is referred to as Razie, to prevent any association with real-world events.

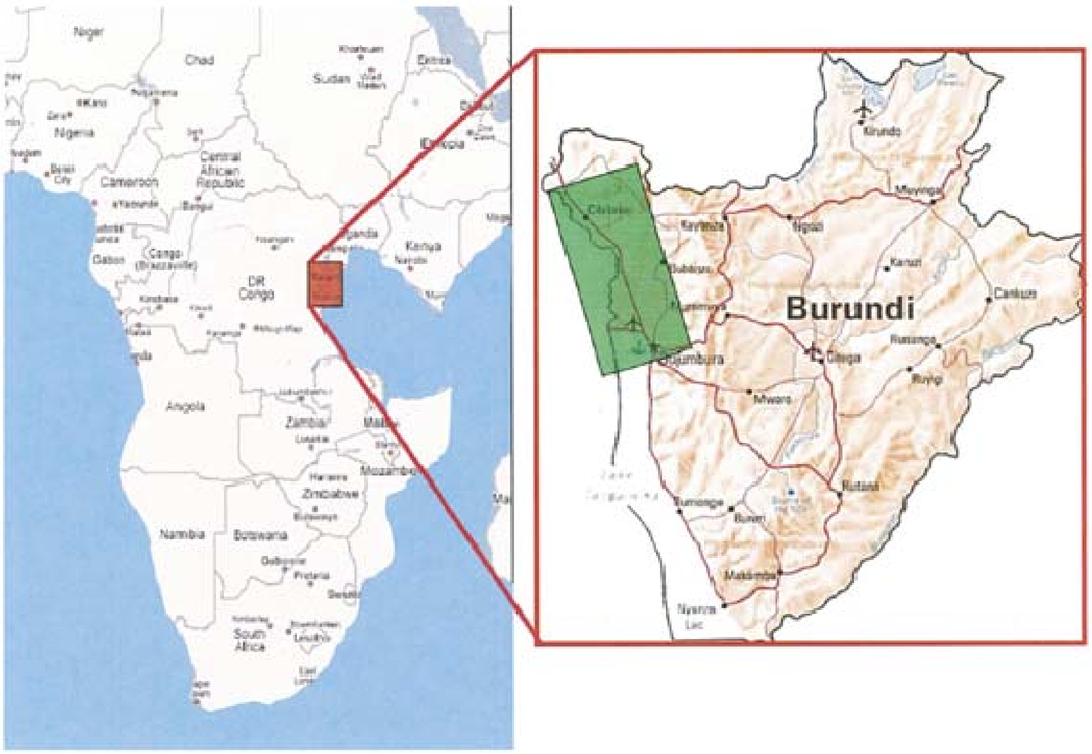



Figure 4. The ECO scenario area is shown in green (From: MCWL ECO Fires Conference PowerPoint Brief, 2009).

### 2. General Situation

The United States has a supportive relationship with the government of Bunduri, a relatively stable democracy in East Africa. The United States has a neutral relationship with the government of Razie, which is led by a corrupt president who has used various nefarious means to stay in power for many years. Within Razie, there is a government opposition movement called the Movement for Democratic Change (MDC). In the latest elections, the leader of the MDC won the popular vote, but the sitting president refused to recognize the election results. As a result of internal and international pressures, the two parties reached a power-sharing agreement with the president remaining in place and the winner of the elections serving as prime minister. After a failed assassination attempt on the prime minister, in which the president's followers were implicated, the president dissolved the national government and instituted martial law. The prime minister fled to the east of Razie with his MDC followers. The MDC's military arm, the Manicaland Peoples Force (MPF), rebelled and took control over Manica Province in Eastern Razie. The former prime minister announced the formation of the independent state of Manicaland and declared war against Razie. Additionally, he declared Manica tribal lands within Bunduri as a part of Manicaland, and the MPF crossed into western Bunduri.

After the incursion into Bunduri, small bands of MPF killed a number of Bunduri police and government officials. Relying on tribal affiliations, the MPF appealed to the Bunduri populace for support. Civil unrest erupted, the president of Bunduri declared martial law, and the Bunduri Armed Forces (BAF) mobilized to restore order. A BAF battalion deployed to take on the MPF, but the disorganized, poorly-led battalion was beaten. The president of Bunduri, fearing the collapse of his government and his inability to stop the MPF, appealed to the U.S. for military intervention.

In response to the appeal for help, the United States established Joint Task Force East Africa and deployed the 15th MEU to the area. The 15th MEU was assigned the AO denoted in Figure 5. The Joint Task Force mission is to contain the international incursions by the Razie MDC in order to ensure stability of the East African subcontinent. The 15th MEU's mission is to clear the MPF militia forces in zone and restore the international border with Razie, in order to support the BAF's stabilization efforts. The MEU commander's concept of operations breaks up the MEU mission into three phases:

- **Phase 1: Ship-to-Objective Maneuver.** Deploy forces into Manicaland in western Bunduri in order to seize population centers and clear these of MPF.
- **Phase 2: Clearance Operations.** 15th MEU forces initially concentrate on denying movement to MFP militia through ISR and ground/air interdiction operations. Once MPF maneuver is limited, 15$^{th}$ MEU will extend ISR to outlying areas and conduct limited offensive operations against remaining MPF concentrations. This phase ends when MPF

militia forces operating within the 15th MEU AO no longer pose a threat to the local population, the international border is restored, the ground combat element is prepared to transition security responsibilities to government of Bunduri forces, and the MEU is postured to transition to support and security operations.

- **Phase 3: Transition to Support.** Stability and Reconstruction Operations – This phase commences with the initial transition of control/security in the AO to the government of Bunduri.

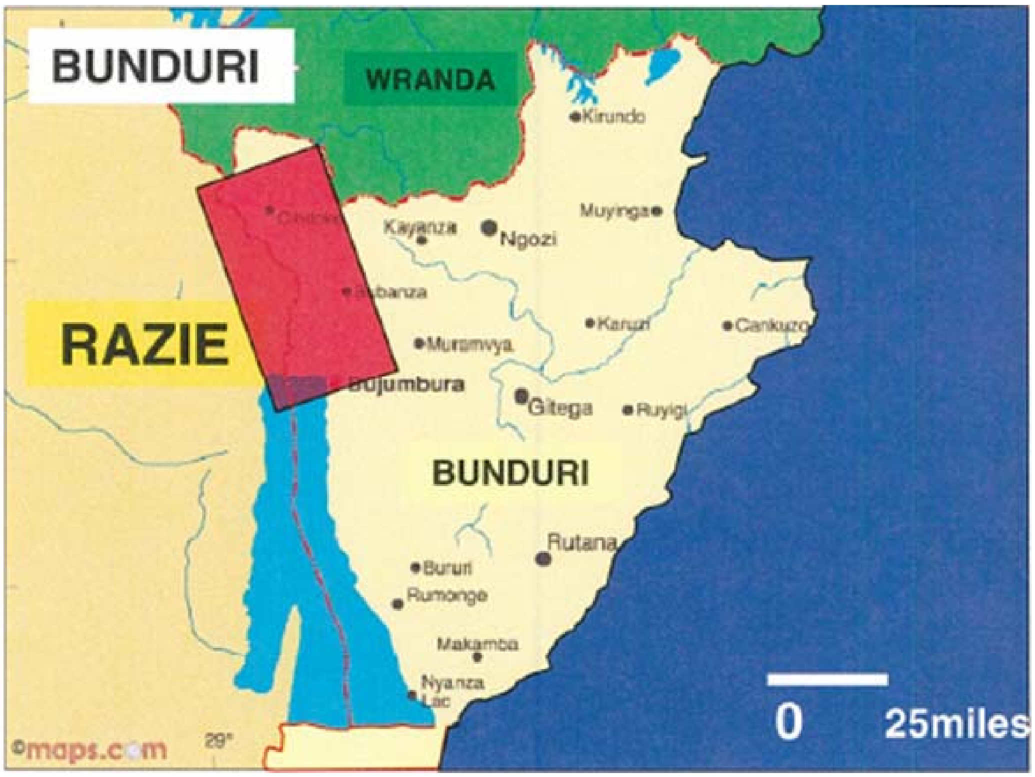



Figure 5. The 15th MEU area of operations is denoted by the red box (From: MCWL ECO Fires Conference PowerPoint Brief, 2009).

The ground combat element in this scenario is Battalion Landing Team 1st Battalion, 1st Marine Regiment (BLT 1/1), which contains three enhanced companies. The BLT commander divided his AO into company-level areas of responsibility (AORs) and assigned them tasks aligned with the MEU commander’s phases listed above.

This thesis considers Alpha Company, one of the enhanced companies, and also the main effort through Phase 2. The scenario begins towards the end of Phase 2. The MPF forces have been driven from Alpha Company’s AOR, but they continue to make incursions across the border to influence the local populace and to harass friendly forces. For the purpose of keeping the simulation modeling within a realistic scope, only Alpha Company is modeled, and, since they are the main effort, they have the luxury of receiving the priority of support from the MEU's assets. The BLT AO is shown in Figure 6.

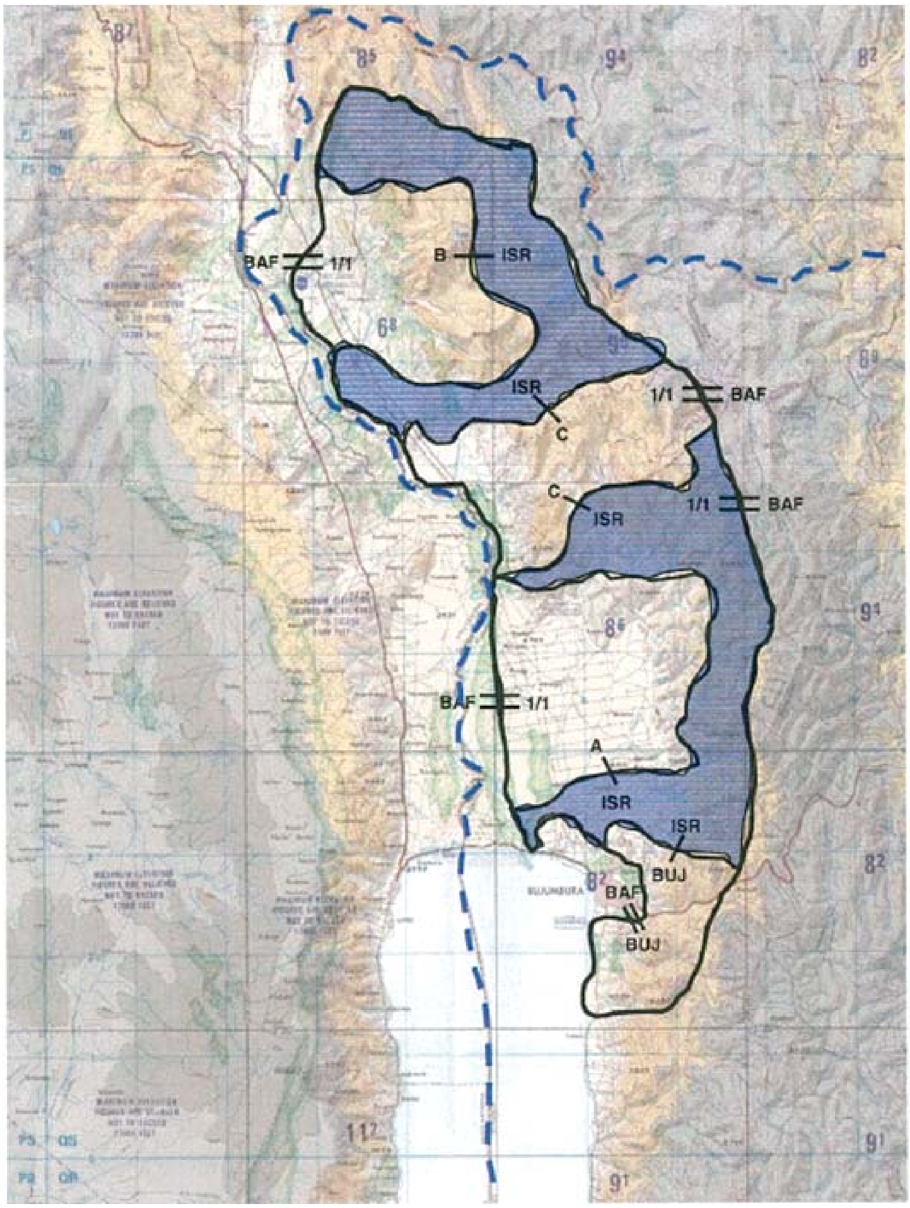



Figure 6. BLT 1/1 AO divided into company-level AORs (From: MCWL ECO Fires Conference PowerPoint Brief, 2009).

### 3. Special Situation

#### *a. Enemy*

Higher headquarters estimates the 3,000-4,000-strong MPF to be armed with substantial small arms supplied by defecting Razie National Army forces. These arms include rocket-propelled grenades, 7.62mm and 12.7mm machine guns, and 81mm mortars. The MPF is capable of placing mines and improvised explosive devices (IEDs). They may have a limited number of SA-7 surface-to-air missiles, but they have not yet demonstrated this capability. They are typically foot-mobile forces, but they also have commercial 4×4 vehicles that can be fitted with medium or heavy machine guns. While little is known about their organizational structure, the MPF is loosely organized at the small-unit level into squads, platoons, and possibly companies. It is unlikely that they are effectively organized beyond the company level. At the height of the incursion, it is estimated that there were 1,000 MPF forces in Bunduri. They employ effective, decentralized guerrilla tactics in tactical units from as small as 4–6 personnel to as large as 12–15 personnel. Forces in excess of 15 personnel have been rare in Bunduri. The MPF was able to effectively coordinate a series of up to 50 small units to defeat the BAF battalion discussed previously. The MPF has proven to be committed and ruthless in combat. There are no longer established MPF positions in the Alpha Company AO. All MPF incursions are thought to originate from across the border in Razie. Although the MPF has left the Alpha Company AO, they are still attempting to influence the local populace by making cross-border incursions and harassing the U.S. forces in the area.

#### *b. Friendly*

Alpha Company is an ECO-capable unit that has been operating in the southern part of BLT 1/1's AO for six weeks. They have cleared the enemy forces in their zone and are preparing to transition to stability operations. Despite the combat operations, their losses have been minimal and they have received replacements from the battalion, so they are currently at full strength. They also have the standard augment of personnel from the battalion that even non-enhanced companies receive. Since they are the ground combat element main effort, they enjoy the priority of support from the 15th MEU.

### 4. Mission

The mission of Alpha Company is to clear the MPF from within their assigned AO in order to set conditions to conduct support, stability, and reconstruction operations.

### 5. Execution

Alpha Company will establish three platoon positions within the AOR, which are shown in Figure 7. From these positions, they will conduct patrols and checkpoints to monitor enemy activity and engage any MPF forces that move into the area. Platoon positions will be mutually supportive where possible, and will cover their assigned sectors with observation and fires.


Figure 7. Alpha Company AOR. The white lines and Route 5 road roughly outline the AOR, approximately 344 square miles. The company headquarters is co-located with 2nd platoon.

### 6. Administration and Logistics

The 15th MEU aviation assets will resupply the company. Delivery will be in the vicinity of the platoon positions and/or other precoordinated locations. The battalion and MEU supporting assets are located at the forward arming and refueling point (FARP), 70 kilometers to the east-southeast of the company headquarters. Casualty evacuations will be by helicopter.

### 7. Command and Signal

The 15th MEU headquarters is located on a ship off the coast of Bunduri. The battalion headquarters is located at the FARP. While the other companies are technically a part of the scenario, they will not be modeled in the simulation. Alpha Company will maintain a common operational picture at the CLOC. Fire support requests, logistics requests, and casualty evacuation requests will all be to the battalion headquarters via radio networks. Intracompany communications will also be via radio networks.

## D. THE MAP AWARE NON-UNIFORM AUTOMATA (MANA) COMBAT SIMULATION TOOL

The remainder of this chapter will describe the MANA modeling environment and how this research implements the scenario into MANA. Readers interested in more information than is provided hereafter should consult the *MANA version 4 User's Manual* and the *MANA-V Supplementary Manual*, both available through the Simulation Experiments and Efficient Designs (SEED) Center at the Naval Postgraduate School (NPS).

### 1. What is MANA?

MANA is an agent-based distillation model developed at New Zealand's Defence Technology Agency, beginning in 2000. The developers, inspired by the MCWL Project Albert agent-based models (ABMs) ISAAC and EINSTein, began work on MANA after it became apparent that purely physics-based models could not adequately analyze the intangible aspects of combat, such as $C^2$ and situational awareness (SA) (McIntosh, Galligan, Anderson, & Lauren, 2007). In MANA, the agents are:

- **Map Aware:** They track their relative position on the terrain map, and to other agents through sensors and communication links.
- **Non-Uniform:** Agents can be defined uniquely with any number of different behavior parameters, weapons, sensors, communications links, and other capabilities.
- **Automata:** Agents can change states after defined trigger events. In each state, an agent reacts independently, depending on its parameter settings.

The *MANA version 4 User's Manual* (2007) further explains:

- MANA is in a general class of models called Agent-Based Models (ABMs). ABMs have the characteristic of containing entities that are controlled by decision-making algorithms. Hence, an agent-based combat model contains entities representing military units that make their own decisions, as opposed to the modeller explicitly determining their behaviour in advance (p. 4).

- To differentiate MANA (and ISAAC/EINSTein, etc.) from highly detailed models that can also use agents, MANA and the like are sometimes called Agent Based Distillations (ABDs). This reflects the intention to model [only] the essence of a problem (p. 5).

- MANA falls into a subset of these models, called cellular automaton (CA) models. CA models have their origin in physics and biology. The famous Ising model of magnetic spin alignment is an example of such a model in physics, while Conway's 'Game of Life' is an example of a CA model designed to explore biological ideas (p. 5).

- MANA and other CA models are often called complex adaptive systems (CAS) because of the way the entities within them react with their surrounding[s]. Some properties of MANA and CAS combat models generally are:

    - The "global" behaviour of the system "emerges" as the result of many local interactions.

    - They are an example of a process of feedback that is not present in "reductionist", top-down models.

    - They cannot be analysed by decomposition into simple independent parts.

    - Agents interact with each other in non-linear ways, and "adapt" to their local environment. (p. 5)

- The MANA model is an attempt to create a complex adaptive system for some important real-world factors of combat such as:
    - Change of plans due to the evolving battle.
    - The influence of situational awareness when deciding an action.
    - The importance of sensors and how to use them to best advantage (p. 5).

### 2. Why MANA?

Since its introduction, MANA has been through a number of upgrades and is now a mature application with a user-friendly graphical user interface and wide range of capabilities. MANA's excellent user's manual makes it easy to learn, and models can be rapidly built with full user control over agents, weapons, communications, and sensor parameters. Additionally, the user has control over terrain and elevation settings, so the model can incorporate line-of-sight calculations, making scenarios more realistic. The latest release, MANA version 5, incorporates a vector-based movement scheme, thus eliminating the need for the user to convert distance-related attributes into pixels (McIntosh, 2009). The developers are responsive and many NPS theses have used MANA as their primary modeling tool.

Because MANA is a non-physics-based distillation of reality, it is ideally suited for exploring the intangible aspects of combat. This is primarily done using data farming techniques by running the simulation thousands of times, while changing parameters of interest in order to statistically evaluate the model's MOEs. MANA simulations are closed-form to allow for this type of analysis, and many desired MOEs are automatically reported in MANA's output file. MANA should be used to answer questions regarding trends, factors of possible importance, or a range of possibilities, rather than for giving precise estimates for predictive questions based on only a few runs of a model.

MANA does have limitations. Because there are so many variables, the user must be attentive to the interactions and consequences of model changes. This requires incremental changes to the model during the building/debugging process, and even then, unexpected and inexplicable behavior can result. While building the model for this thesis, the author experienced this problem many times and had to find creative solutions. One such problem even led to the developers issuing an update to the software. Details can be found in Appendix F.

## E. CHARACTERISTICS OF THE SIMULATION MODEL

This section describes how this thesis implements the previously described scenario in MANA. It starts by describing the goal of the model and how it works conceptually. It then follows with a description of model specifics including the terrain, enemy forces (red agents), friendly forces (blue agents), and the way in which logistics support is incorporated into the model. Finally, this section concludes with the assumptions and abstractions necessary for this model.

### 1. Goal

This simulation models Alpha Company in their AOR near the end of Phase 2. The goal is to determine how effectively the MEU aviation assets are able to logistically support the enhanced company. Specific MOEs are the amount of time that blue agents spend in a "fuel out" state (signifying that they are out of supplies) and the number of enemy killed (more is better). Primary factors of interest include the MEU aircraft mix available to support the company, the distance from the company positions to the seabase, and the time required to launch a helicopter once a rapid support request is received. By varying these and other factors, and by using the data analysis techniques discussed in the next chapter, this thesis will explore the logistical demand an enhanced company will have on a MEU's aircraft.

### 2. Conceptual Model

This model can be represented as an inventory queuing model shown in Figure 8. There are three platoon positions within the Alpha Company AOR. At each position there is a "supply tank" representing the supplies available to the platoon. A supply unit is an aggregated entity, representing what one fire team would use in one day, and includes food, water, ammunition, fuel, etc. Each fire team begins the simulation carrying one day of supply (DOS). Each platoon supply tank holds enough supply units to serve two additional DOS to every fire team at that position, so that there are a total of three DOS available at the beginning of the simulation. As the simulation runs, the fire teams consume supplies at differing rates, depending on combat intensity. When at least two of the three fire teams in a squad are out of supplies, they return to the supply tank. If the tank has supplies, it serves the squad. When a supply tank runs out of supplies (i.e., the fire teams only have one carried DOS remaining), a request is sent to the MEU for a resupply. If aircraft assets are available, they resupply the tank. If a squad returns to a tank to find it empty (i.e., the resupply request is yet unfilled), it waits at the tank until it has been resupplied before continuing on its mission.

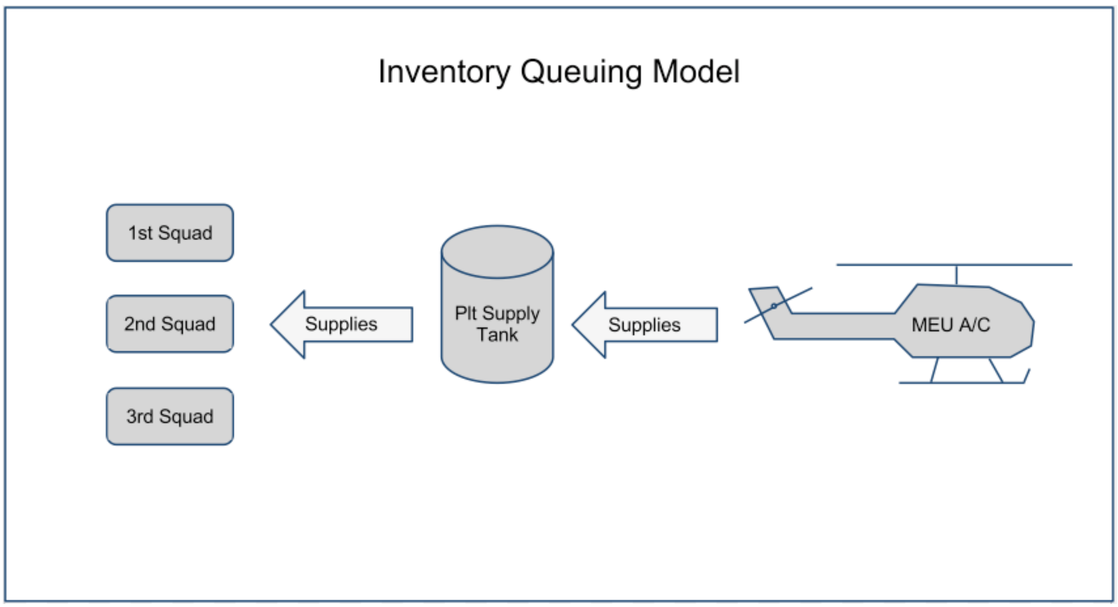



Figure 8. The scenario inventory queuing model.

### 3. Terrain and Scale

Because MANA is a time-step model, there must be a mapping from real time and space into simulation time and space. This mapping affects agent movement speed, weapon ranges and firing rates, and sensor ranges among other parameters. In MANA version 5, the user simply defines the battlefield dimensions in the units of his/her choosing and the spatial mapping needed for movement calculations is handled by the model. In the implementation of this scenario, the battlefield "Global Map Size" is defined to be 33 kilometers wide by 27 kilometers high, as shown in Figure 9. Once the battlefield size is set, there are three map layers that can be handled by MANA: the background map, the terrain map, and the elevation map.

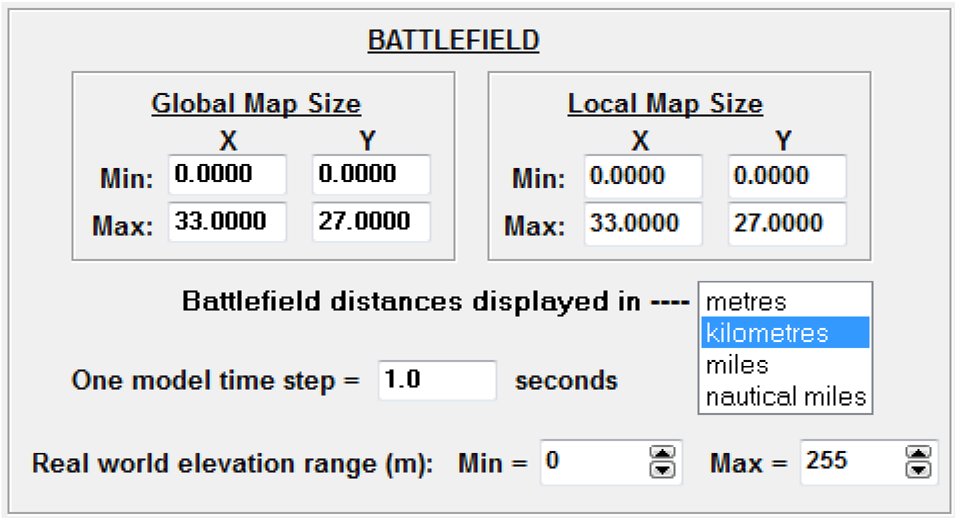



Figure 9. The model battlefield setting options in MANA version 5.

The background map is a bitmap image that is solely for the user's benefit and has no bearing on simulation calculations. It is helpful for arraying forces on the battlefield, specifying waypoints, and setting up the terrain map among other things. This simulation uses a 1:50,000 topographical map of the Alpha Company AOR as the background image as shown in Figure 10. One nice feature of using a topographical map is the ease of setting the battlefield dimensions to correspond with the map dimensions, as was done in this case.

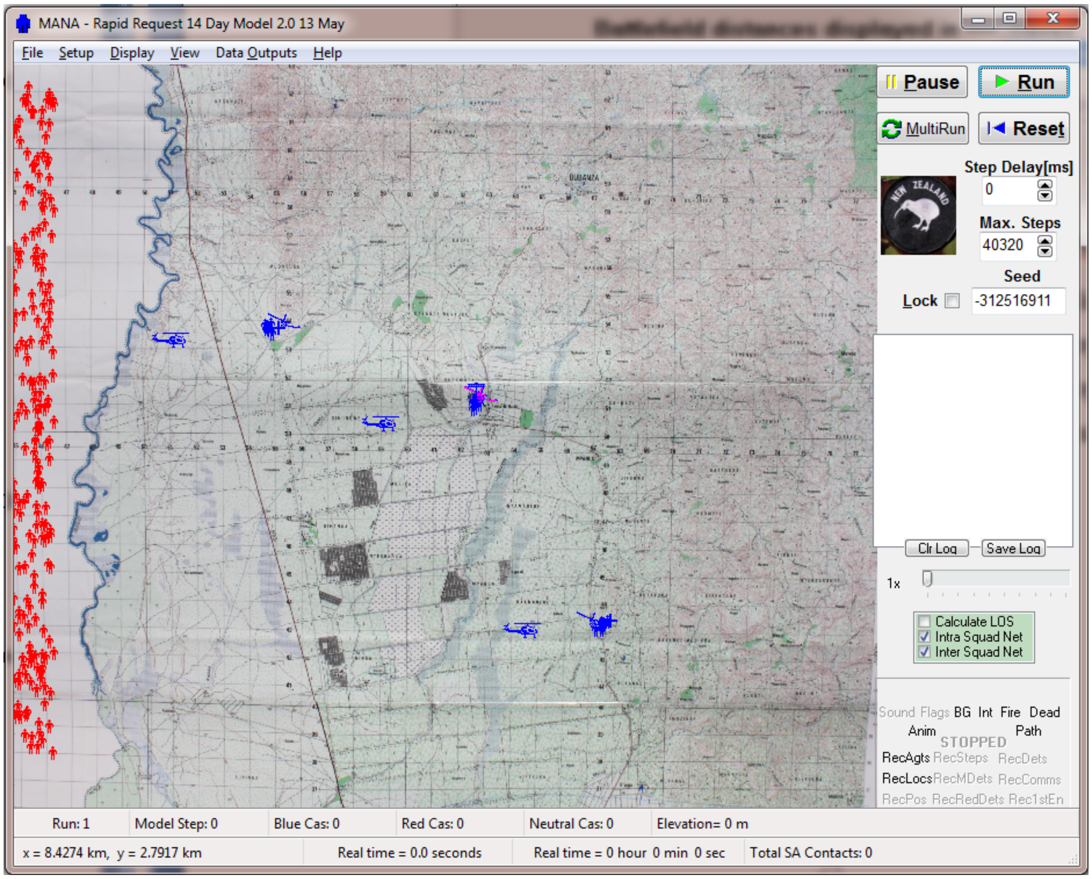



Figure 10. The simulation model background map [Best viewed in color].

MANA uses the terrain and elevation maps to determine a number of calculations as the scenario progresses. Included in these are ease of movement and line of sight. The terrain map is a bitmap image where various colors represent terrain features like walls, roads, hills, and vegetation. The different colors correspond to ease of movement, as well as cover and concealment parameters for MANA agents. For example, agents can be set to have a preference to move along easy routes, like roads, or towards cover when in enemy contact. The elevation map is a bitmap image that uses gray-scale colors to signify elevation, which affects agent line-of-sight calculations. Black is the lowest terrain and white is the highest. In this simulation, the highest elevation is 1,060 meters above sea level. Each agent has a specified sensor height, so agents can only see one another if there are no terrain features that provide concealment or elevation differences that would prevent the agents from having line of sight. The simulation terrain and elevation maps can be seen in Figure 11.

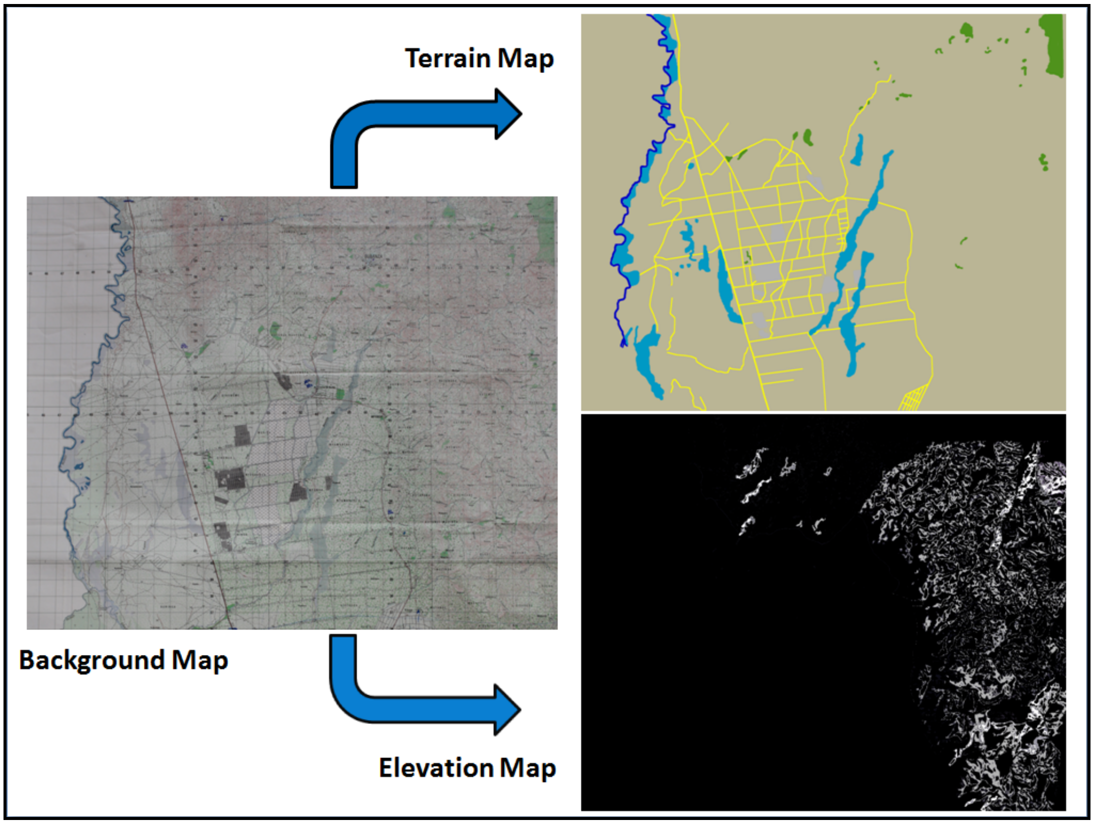
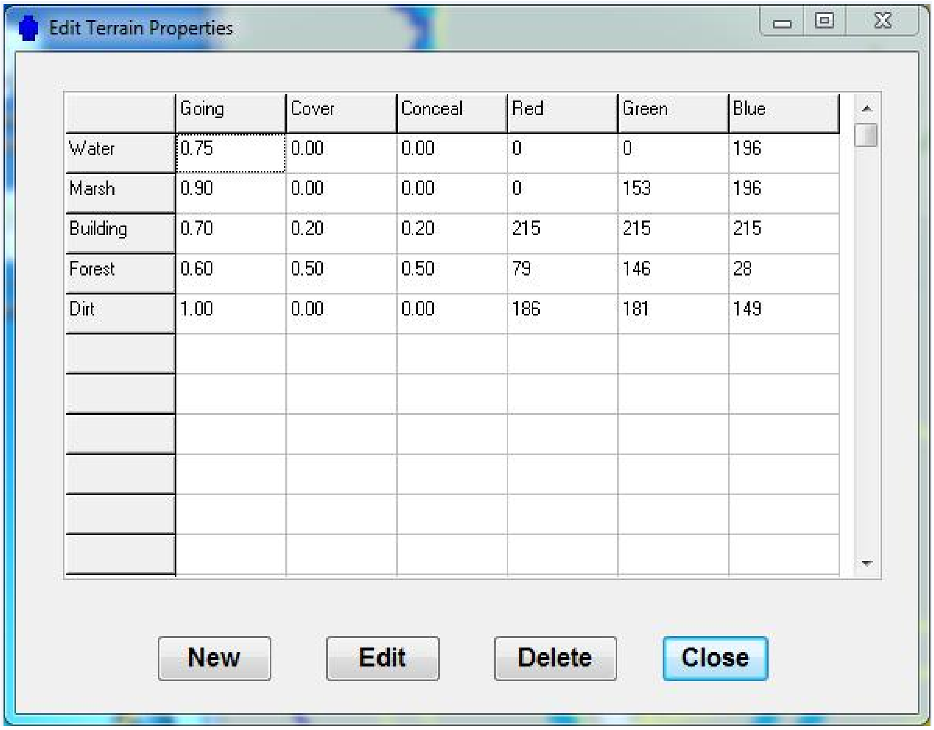



Figure 11. The terrain and elevation maps used by MANA [Best viewed in color].

The terrain characteristics used in this simulation can be seen in Figure 12. For "Going," a value of 1.00 means that agent movement is uninhibited by terrain, whereas a value of 0.00 means that an agent cannot move through or occupy that space. Similar conditions apply to cover and concealment. Values between the extremes are treated as different weightings, which are applied as multipliers against the other parameters affecting movement, visibility, and firing. For example, an agent moves at 60% of maximum speed (going), has a 50% probability of not being seen (concealment), and a 50% probability of the terrain blocking a shot (cover) per time step in forested terrain (assuming perfect enemy sensors and weapons). The red-green-blue values determine the color of the terrain feature on the map.




| | Going | Cover | Conceal | Red | Green | Blue |
|---|---|---|---|---|---|---|
| Water | 0.75 | 0.00 | 0.00 | 0 | 0 | 196 |
| Marsh | 0.90 | 0.00 | 0.00 | 0 | 153 | 196 |
| Building | 0.70 | 0.20 | 0.20 | 215 | 215 | 215 |
| Forest | 0.60 | 0.50 | 0.50 | 79 | 146 | 28 |
| Dirt | 1.00 | 0.00 | 0.00 | 186 | 181 | 149 |

Figure 12. The simulation terrain characteristics.

In addition to terrain calculations, MANA has the ability to model multiple seconds per time step. This simulation uses 30 seconds per time step, but the agent movement speed conversions are done using Excel rather than MANA to avoid some abnormal behavior (see Appendix B). This scenario runs for 14 days, which equates to 40,320 time steps. Because there are so many time steps, this scenario takes between 40 and 60 minutes to run on modern computers, depending on the simulation parameter values.

### 4. Red Force (Enemy Insurgents)

Insurgents always begin their operations on the Razie side of the border (depicted by the river on the left side of the map in Figure 9). Each agent icon represents a fire team-sized unit (typically four insurgents). Their goal is to infiltrate across the border into Bunduri and move to one of three predetermined waypoints without being killed by the Marines. When engaged by blue forces they will either attempt to break contact and continue to their waypoint or fight aggressively, depending on the simulation parameter settings. Each simulation day, three squads of red agents go active at differing times and move to one of the three waypoints. The red agents' route to the waypoint depends on its random starting position in its homebox. In the experimental design, the number of red agents per group (each agent represents a fire team-sized element) varies from 1 to 15 because 45 fire teams is about a company-sized unit, which is the maximum the MPF is capable of massing in the scenario. A red unit's fire power is equivalent to a blue unit's; however, since the purpose of red units is simply to affect the blue unit's consumption of supplies, a red agent is incapable of killing a blue agent, so the maximum amount of stress on the MEU supporting assets is always maintained.

### 5. Blue Force (Marine Enhanced Company)

Alpha Company is arrayed as shown in Figures 7 and 10. There are three platoon positions: 1st, 2nd, and 3rd, from south to north, respectively. Each platoon has three squads of three fire teams each. Like the red agents, each blue icon in MANA represents a fire team, of which there are three per squad. Since the scenario mission dictates that the enhanced company cover such a large AOR, at each position two squads continuously patrol to a set waypoint and return to the platoon base, while the other squad remains to provide base security. In theory, one squad patrolling for six hours, providing base security for six hours (this would be considered "down time"), and then patrolling for another six hours is sustainable for a prolonged period of time. Colonel Ed Lesnowicz, a retired Marine artillery officer with 36 years of experience, successfully used this scheme of maneuver during operations in Somalia (Colonel Lesnowicz, personal communication, May 2010). Since a company is equipped with three 60mm mortar tubes, there is one mortar tube at each platoon position. In addition, the company also has two Expeditionary Fire Support Systems (EFSS) co-located with the company headquarters and 2nd platoon. The EFSS attachment is consistent with how an enhanced company would be deployed (personal conversation with Mr. Christopher C. Carolan, MCWL). The mortar teams and two EFSS support teams each represent a fire team's worth of additional personnel.

As the squads perform their missions, they use one unit of supply per time step. When their sensors detect enemy presence, they use two units of supply; when they are engaged with the enemy, they use three units of supply per time step. Varying supply usage due to differing levels of combat intensity is consistent with real-world operations (based on the author's personal experience as a logistics officer during OIF). While the platoon positions all start with three days of supply, they may actually consume the supplies much faster depending on the level of combat intensity, thus putting greater demand on the MEU's supporting assets.

### 6. Logistical Support

In order to get the refueling behavior to work properly, this simulation creatively uses MANA's state, sensor, and weapons capabilities. As previously described, logistics support for the platoon positions is modeled as a supply tank that resupplies the squads. When a squad goes into a "fuel out" state, its primary behavior is to return to base for a resupply. The fuel tank has a sensor that can see "fuel out" squads and a secondary "weapon" that can shoot them (this weapon does not kill or injure the blue agent, it simply triggers a state change). When a squad is within range of the tank's weapon, it is shot if the tank has ammunition (i.e., supplies) remaining. When shot, the agent switches into the "shot at" state, refuels itself (using a negative refueling rate), and then continues on its mission. When the tank has fired all of its ammunition, which is used to represent the tank's supply capacity, it changes states into one visible by the resupply agent (the MEU aircraft), is shot at by the resupply agent, and reverts back into its default state with a full load of ammunition. When a tank runs out of ammo, it must wait the amount of time it takes to load a helicopter and transit the distances to the platoon position from the seabase. While this is occurring, any squads that need supplies will have to wait. If they are not available to perform their missions, the red agents are less likely to be killed, which is why proportion of enemy killed and time in a fuel out state are key MOEs.

### 7. Data Sources, Abstractions, Assumptions, and Validation

Since it is not possible to model reality exactly, it is important to use data sources and assumptions that allow a model to be as accurate as possible, so that useful information may be gleaned from the simulation process. This model uses a scenario provided by MCWL and validated by Colonel Goulding, whose input proved invaluable.

For example, when asked if an AOR of approximately 344 square miles would be realistic, he replied, “344 sq miles is hardly unrealistic; 3dBn 3dMar had an AOR of 17,508 miles on its recent deployment…” (V. J. Goulding, personal communication, March 11, 2010). In addition to validating the realism of the scenario, the author developed the MANA abstraction of the scenario in concert with other modeling and simulation experts. Mary McDonald, a MANA expert and former Marine officer, understood the scenario and was instrumental in incorporating it into MANA. The author also led a team of experienced modelers at the spring 2010 International Data Farming Workshop in Monterey, California, who assisted in model development. This scenario demands a level of tracking precision that pushes MANA’s limits, so when limitations with MANA itself prevented further progress, Mark Anderson, a MANA developer, made required updates and produced a new version of MANA capable of running the desired model. Finally, the model development was briefed weekly to Dr. Tom Lucas, Ph.D., a combat modeling expert at NPS. The following paragraphs describe some modeling assumptions necessary for the simulation.

This thesis needed to determine how many aircraft would be needed to supply two DOS to a platoon position. Using planning factor data primarily provided by the Operations Analysis Division (OAD), Marine Corps Combat Development Command (see Appendix E), the total weight requirement for one platoon position per day is 4,483 pounds, as shown in Table 1. Additionally, Table 2 shows the specific weight calculations for ammunition, fuel, and water.

| 1 Day of Supply per Platoon (Plt) Weight Calculation | | | |
|---|---|---|---|
| **Supply Class** | **Description** | **Lbs/Plt/Day** | **Planning Factor Source** |
| 1 | Food | 268 | OAD |
| 1 | Water | 2806 | OAD |
| 2 | Clothing | 100 | MAGTF Planner's Manual |
| 2 | Batteries | 260 | OAD |
| 3 | Fuel | 158 | Spreadsheet Analysis |
| 4 | Construction Materials | 182 | MAGTF Planner's Manual |
| 5 | Ammo | 355 | MCO 8010.1E |
| 6 | Personal Demand | 163 | MAGTF Planner's Manual |
| 8 | Medical Supplies | 71 | MAGTF Planner's Manual |
| 9 | Repair parts | 120 | OAD |
| | **Total Lbs/Plt/Day** | **4483** | |

Table 1. The total weight requirements for one platoon of 48 Marines per day.

| Ammo Calculations per Platoon (Plt) | | | | |
|---|---|---|---|---|
| Item | Weight (lbs) | Daily Assault Rate (MCO 8010.1E) | Weapons per Plt | Lbs/Plt/Day |
| 5.56mm | 0.026 | 8 | 30 | 6 |
| 40mm Grenade | 0.5 | 3 | 10 | 15 |
| 5.56mm linked | 0.031 | 27 | 10 | 8 |
| 60mm Smoke | 4 | 9 | 1 | 36 |
| 60mm Illum | 4 | 4 | 1 | 16 |
| 60mm HE | 4 | 7 | 1 | 28 |
| 7.62mm linked | 0.055 | 70 | 2 | 8 |
| 120mm Illum | 30 | 3 | 0.66 | 59 |
| 120mm Smoke | 30 | 4 | 0.66 | 79 |
| 120mm HE | 30 | 5 | 0.66 | 99 |
| | | | **Total Lbs/Plt/Day** | **355** |

| Fuel Calculations per Platoon | |
|---|---|
| ITV miles per gallon | 17 |
| Miles/day/ITV | 50 |
| Lbs/gal JP8 | 6.7 |
| Lbs/day/ITV | 20 |
| ITVs/platoon | 8 |
| **Total Lbs/Plt/Day** | **158** |

| Water Calculations per Platoon | |
|---|---|
| Gallons/marine/day | 7 |
| Lbs/gallon | 8.4 |
| Lbs/day/Marine | 58.5 |
| **Total Lbs/Plt/Day** | **2806** |

Table 2. The ammunition, fuel, and water weight requirements for one platoon of 48 Marines per day.

After consultation with an experienced Marine Corps helicopter pilot, who referred to the *Naval Air Training and Operating Procedures Standardization Program Manual*, it was determined that an MV-22 Osprey can transport at least 9,362 pounds of cargo to its maximum range in the given scenario conditions. Similarly, a CH-53E can transport 18,000 pounds. For simplicity, this model assumes that no cargo compatibility or bulk size limitations exist. Under this assumption, one MV-22 is capable of carrying enough cargo to supply one platoon position, and a CH-53E can carry enough supplies for two.

Other assumptions are related to communication, weapons, and rates of movement. While MANA is capable of modeling communication shortfalls, for this scenario all communications are assumed to work perfectly throughout the AOR. Movement speed and weapon firing rates are based on 30 seconds real time per time step. Because the movement rate and weapon firing rate conversions are handled outside of MANA, they are provided in Appendices B and C. Weapon ranges and firing rates are aggregated at the fire-team level using data found on http://globalsecurity.org and www.fas.org. Blue and red fire teams have the same capabilities, unless blue patrolling squads are considered to be mounted in vehicles. Under this case, blue weapon ranges and firing rates are extended to be commensurate with mounted crew-served machine gun parameters. When foot mobile, both red and blue agents move at 5 kilometers per hour (kph). When blue agents are mounted on vehicles, they move at 56 kph. Other parameters that could directly impact the model's outcome are varied in the experimental design, as described in Chapter III.

## F. SUMMARY

ECO represents the cutting edge in evolving infantry tactics as the Marine Corps strives to meet future challenges. This research uses the MANA version 5 simulation tool to model a realistic scenario that an enhanced company could encounter. Within the context of this scenario model, an experimental design is used to explore the demand that an enhanced company may have on a MEU's supporting aircraft.

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# III. EXPERIMENTAL DESIGN

## A. INTRODUCTION

In a simulation study, the manner in which the experiments are conducted is very important. If a simulation is run once under a given set of variables, the output will not reveal which factors are important. If a simulation is run multiple times while varying the input parameters in an ad hoc way, the output will reveal which changes result, but may not reveal why those changes occurred. However, if a systematic design of experiments approach is used, the simulation can be run many times, varying the input parameters in such a way that the experimenter is able to draw conclusions about cause and effect from the analyzed results. There are different design choices depending on the model's limitations, the questions of interest, and the time available. Because it would be very time consuming (or impossible) to explore every possible combination of design factors, this research uses a robust DOE method, the Nearly Orthogonal Latin Hypercube (NOLH), which is explained here. This research also uses an analytical technique known as data farming. Developed under MCWL's Project Albert in 1998, data farming is an innovative concept that entails running a relatively simple model, like the one used here, many times, while systematically changing input parameters (Brandstein & Horne, 1998). The resulting data set is then explored statistically to see what patterns and other behaviors emerge. This process can highlight interesting and useful areas of the feasible space and answer many "what if" questions. Additionally, the analyst can perform this technique iteratively to focus on specific parameters and/or questions.

This chapter defines the variables of interest that are changed as the simulation experiment runs, explains the NOLH, and describes the experimental designs this thesis uses to explore and understand the logistical impact an enhanced company will have on a MEU.

## B. VARIABLES OF INTEREST

This section describes the parameters, or design factors, varied during this experiment. There are two types of factors used: controllable and uncontrollable.

Controllable factors (often called decision factors) are those that can be controlled by friendly decision makers, whereas uncontrollable ones cannot. Uncontrollable factors (also known as noise factors), like weather or enemy actions, have an impact on output variability, so they are included in the design. While some factors could arguably fall into both categories, this study does not allow it. For example, an aircraft's speed can be fully controlled by the pilot, but poor weather may limit the speed range the pilot can use. To avoid confusion, this thesis considers decision factors as those typically controllable by the Marines, and noise factors as those typically controlled by the enemy. The decision and noise factors are summarized in Table 3.

| Factor | Range | Description |
|---|---|---|
| Aircraft Mix | Categorical 1..6 | The Aircraft combination used by the MEU to support the enhanced company. |
| Sea Base Distance | 50 to 200 miles in 10 mile increments | The distance of the sea base to the enhanced company. |
| Response Time | 30 to 180 mins in 30 min increments | The time, in minutes, between the MEU receiving the rapid request for support and when the helicopter departs the sea base. |
| EFSS Max Range | 8k or 14k meters | The maximum range of the EFSS system depending on if rocket assisted projectiles are used. |
| Mounted/Dismount Patrol | Categorical 0 or 1 | A binary categorical variable to determine if blue patrolling squads are mounted in vehicles. If mounted, speed, firing rates, and sensor ranges all increase. |
| Number of Agents per Red Squad | 1..15 | The number of fire team agents per red squad. |
| Red Aggressiveness | Categorical 0 or 1 | A binary categorical variable controlling red agent aggressiveness. If aggressive, the red desire to move towards blue agents increases from 0% to 70%. |
| Red Movement Speed in Contact States | 0..5 kph | The speed red agents move when in contact with blue agents. |
| Red Hits to Kill | 1..5 hits | The number of times a blue agent must hit a red agent to kill it. |

Table 3. The variable factors in the experimental design. Decision factors are highlighted in blue and noise factors are highlighted in red [Best viewed in color].

### 1. Decision Factors

#### *a. Aircraft Mix*

Previous analysis calculated the weight of supplies each platoon requires per day at 4,483 lbs (see Chapter II, Section 7). In order to fill a rapid request of two DOS, an aircraft must deliver 8,966 lbs. A MEU composite squadron rates 12 MV-22 Ospreys and 4 CH-53E Sea Stallions. Based on the weight requirement, either platform is capable of resupplying a platoon. In fact, a CH-53E is capable of carrying enough supplies for two platoon positions. If a MEU commander allocates three MV-22s or two CH-53s, there would be sufficient aircraft to resupply all three platoon positions daily without breaking aircrew rest constraints. Of course, a MEU commander can allocate as few as one aircraft to support the company, so this categorical factor defines what feasible combination of helicopters are allocated to support the company. Table 4 shows these combinations.

| Case | Aircraft Mix |
|---|---|
| 1 | 1 MV-22 |
| 2 | 1 CH-53 |
| 3 | 1 MV-22; 1 CH-53 |
| 4 | 2 MV-22s; 1 CH-53 |
| 5 | 3 MV-22s |
| 6 | 2 CH-53s |

Table 4. Aircraft mix combinations.

#### *b. Seabase Distance*

In this scenario, the company positions are approximately 80 miles from the notional coastline. Figure 13 shows this relationship. The seabase supporting the company could be right off the coast, or it could be further out to sea to take advantage of the protection an over-the-horizon position affords.

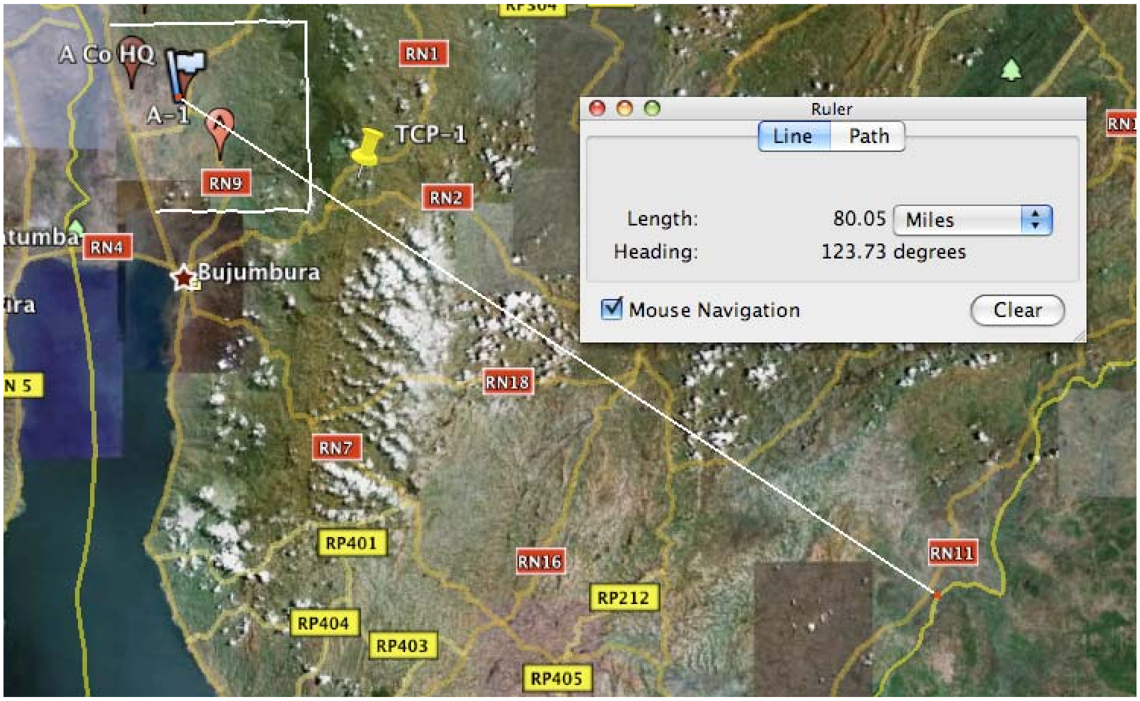



Figure 13. The distance from the Alpha Company headquarters to the notional coastline.

In order to explore a wider range of possibilities than the scenario naturally offers, this decision factor is varied between 50 and 200 miles in 10-mile increments. This factor affects the time delay a tank must wait to get refueled depending on the travel speed of the helicopter serving the tank.

While 200 miles is well within the combat radius of an MV-22, it exceeds the publicized combat radius of a CH-53E. However, Sikorsky, the helicopter's manufacturer, gave a brief at the Expeditionary Warfare Conference in 2001, advertising a future capability to lift 28,000 lbs for 200 nautical miles (nm). See Figure 14 for a PowerPoint slide from that presentation. It is also possible to conduct aerial refueling using tanker aircraft. This makes the 200-mile radius a reasonable number to explore, even when considering CH-53Es.

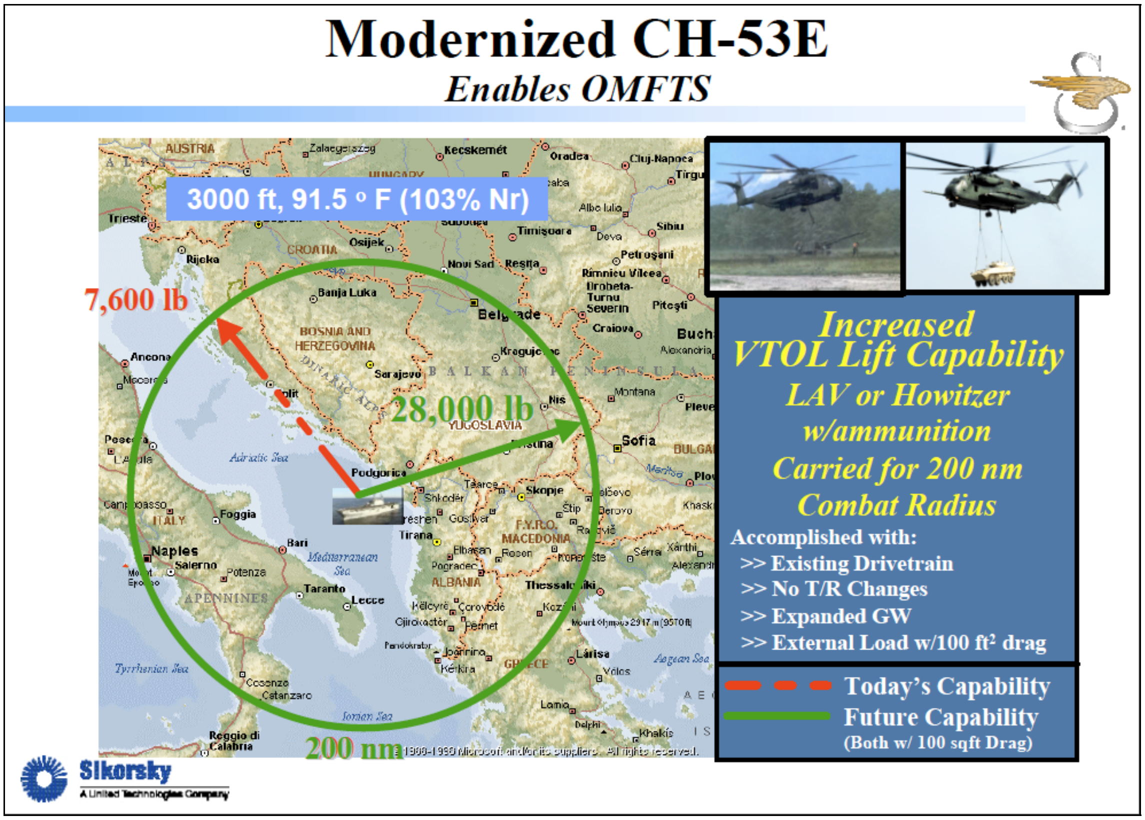



Figure 14. PowerPoint slide showing CH-53E future capability to lift 28,000 lbs for 200 nautical miles (From: Expeditionary Warfare Conference PowerPoint Brief, 2001) [Best viewed in color].

#### *c. Response Time*

This defines the time delay from the MEU receiving the rapid request to the helicopter taking off with the supplies. This factor combines with the distance-based travel time to determine how long a platoon position must wait for a resupply. In MANA, when a helicopter's sensor sees an empty tank (i.e., the MEU gets the resupply request), it goes into a delay state to account for the response time and one-way travel time. Once that period has expired, it briefly goes into a state capable of resupplying the tank. After the tank has been resupplied, the helicopter goes into another delay state to account for the travel time back to the MEU before it can be summoned again.

#### *d. EFSS Max Range*

If the Marines have rocket-assisted projectiles, the maximum range of the EFSS is 14 kilometers (km); otherwise it is 8 km.

#### *e. Mounted/Dismounted Patrol*

This factor is binary categorical variable to determine if blue patrolling squads are mounted in vehicles. A number of parameters are lock-stepped with this variable. If mounted, speed, firing rates, and sensor ranges all increase to account for the improved mobility, crew-served weapons, and higher vantage points vehicles offer.

### 2. Noise Factors

These are uncontrollable by blue forces. The purpose of these factors is to vary the level of combat intensity and the demand placed on the MEU's assets.

#### *a. Number of Agents per Red Squad*

This is the number of fire team agents per red squad. The range is from 1 to 15.

#### *b. Red Agent Aggressiveness*

This factor defines how aggressive red agents are when they are in contact with blue agents. The values are either 0% aggressive, which means they want to break contact with blue agents, or they are 70% aggressive and will want to fight blue agents.

#### *c. Red Agent Movement Speed in Contact States*

This factor determines how fast red agents move when they are in contact with blue agents. The range is from 0 to 5 kph.

#### *d. Number of Hits to Kill*

This factor varies the number of hits it takes a blue agent to kill a red agent. The range is from 1 to 5 hits.

## C. THE EXPERIMENTS

This thesis uses an iterative approach to build the experiments. First, it builds a MANA model, tests and debugs the model, and runs a trial experiment. Then, it fine tunes the design and runs another experiment. Finally, it selects variables of interest to focus on and runs subexperiments for more detailed analysis of the design space. This section begins by describing the foundation of the experimental design, the NOLH. It then describes the iterative experiment process in detail.

### 1. The Nearly Orthogonal Latin Hypercube (NOLH)

This research uses the NOLH space-filling experimental design technique developed by Lieutenant Colonel Thomas Cioppa, USA, at NPS in 2002. The NOLH technique lets the experimenter efficiently explore the design space of a large number of variables in a relatively small number of runs using nearly orthogonal design columns (Cioppa, 2002). A design point is a unique vector of values corresponding to the variable factors and their respective range of possible values. When using a full factorial design (every possible vector is considered), the number of design points can quickly become unwieldy, if not practically impossible, to deal with. For example, using just the high and low values of the factors listed in Table 3 would require $2^9$ or 512 design points. This experiment explores the same factors using 129 design points, without being limited to just high and low values. This difference becomes significant because one replication can take up to an hour to run. By keeping the design columns nearly orthogonal, the correlation, or linear relationship, between factors stays low so parameter estimates using a linear regression model can be estimated nearly independently. For additional details, including the algorithms behind the NOLH technique, the reader is directed to LTC Cioppa's dissertation.

### 2. Experimental Design

This research uses a spreadsheet tool developed by Professor Susan Sanchez of the Operations Research Department at NPS to generate the NOLH design. This tool can generate designs using up to 29 factors with 257 design points (Sanchez, 2005). Using the design factors and ranges in Table 3, the NOLH tool produced a 129-point design (represented in Figure 15), and a scatter plot matrix showing the NOLH nearly-orthogonal and space-filling properties. Each box depicts the pairwise projections of the design points for two factors. When the boxes are filled with data points, the design samples across the ranges of the two factors, and the space-filling property is apparent. Boxes that show just a few bands of data points correspond to discrete factors and still show that most if not all pairwise combinations are accounted for. Had there been any highly correlated pairs, a linear dependence would have been obvious. An analysis showed the highest absolute correlation between any two factors to be 0.089. This helps to ensure that confounding effects are minimal in the model.

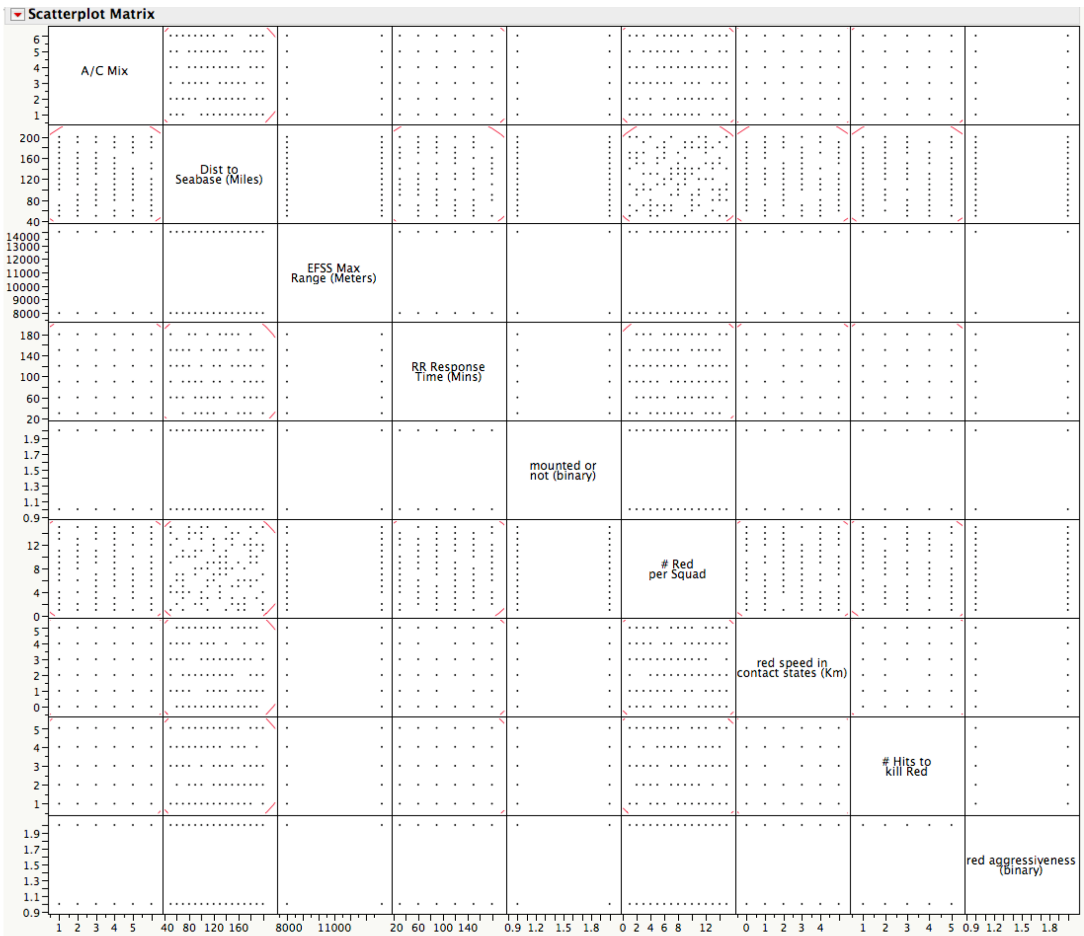



Figure 15. A scatter plot matrix of the experimental design.

For this design, each design point is replicated 20 times with a different random number seed. Each design point vector of factor values was used in the MANA ECO model, so a total of 2,580 battles were simulated. An initial analysis showed that helicopter mix and distance to seabase were being dominated by other variables, so a subexperiment that held all variables constant except for helicopter mix and distance to seabase was run 30 times for each design point. The subexperiment used a 96-point, full-factorial design because of the greatly reduced input space. Table 5 shows the factor values that were held constant. A detailed discussion of why this subexperiment was conducted is found in Chapter IV. Detailed tables of the experimental designs are found in Appendices F and G.

| Factor | Subexperiment |
|---|---|
| **Helicopter Mix** | **1..6** |
| **Seabase Distance** | **50 to 200 miles by 10** |
| Response Time | 1 hr |
| EFSS Max Range | 8,000 km |
| Mounted/Dismount Patrol | Dismounted |
| Number of Agents per Red Squad | 8 |
| Red Aggressiveness | 70% |
| Red Movement Speed in Contact States | 3 kph |
| Red Hits to Kill | 2 |

Table 5. The fixed values for the subexperiment. Variable factors and their ranges are in bold. Decision factors are highlighted in blue, and noise factors are highlighted in red [Best viewed in color].

## D. RUNNING THE EXPERIMENT

Running this experiment using MANA is a relatively straightforward process. The base case MANA scenario, in eXtensible Markup Language (XML) format, and the DOE file, in comma-separated value (CSV) format, were entered into a software program called XStudy, written by SEED Center Research Associate Steve Upton, which enables the user to map each column in the design file to a specific parameter in MANA, using XPaths. Other details about the study design, such as version of MANA and number of replications per design point, are also entered into this tool, yielding a single Study.xml file. This file is used by another program called oldmcdata, also written by Steve Upton, which automatically updates the MANA XML file, producing a separate XML scenario file for each of the different factor combinations, and then launches these on a high-performance computing cluster.  This is done to automate the parallel implementation of the MANA simulated runs and subsequently collect the output data into a single CSV file.

Since the memory requirement for running this scenario was high, these XML files were then ran on a cluster of the 37 highest-performing processors owned and operated by the SEED Center at NPS.  Each replication took approximately 35 minutes using a single processor.  One hundred twenty-nine design points, with 20 replications each, equates to 2,580 simulation runs.  This number of runs would have taken over 62 days to complete using a single processor.  Using the 37-processor cluster, however, it took just under 5 days, emphasizing the advantage of using NOLH experimental design in combination with the computational power of the cluster.

The 129-point design described above was actually the second design this study ran.  The first was a 257-point design that ran 40 replications for each design point.  The experiment ran for over 10 days using all of the processors, including those with less memory.  However, only 5,764 of 10,280 runs returned valid data.  It turned out that the processors with less memory could not handle the simulation, so those processors were excluded, modifications were made to the model, and the number of design points was reduced to complete the experiment under the given time constraints (M. McDonald, personal communication, June 4, 2010).

# IV. DATA ANALYSIS

Using the experimental design described in Chapter III, MANA produced a large amount of data. This chapter describes the data collection and processing procedure, and provides a detailed analysis of the collected data.

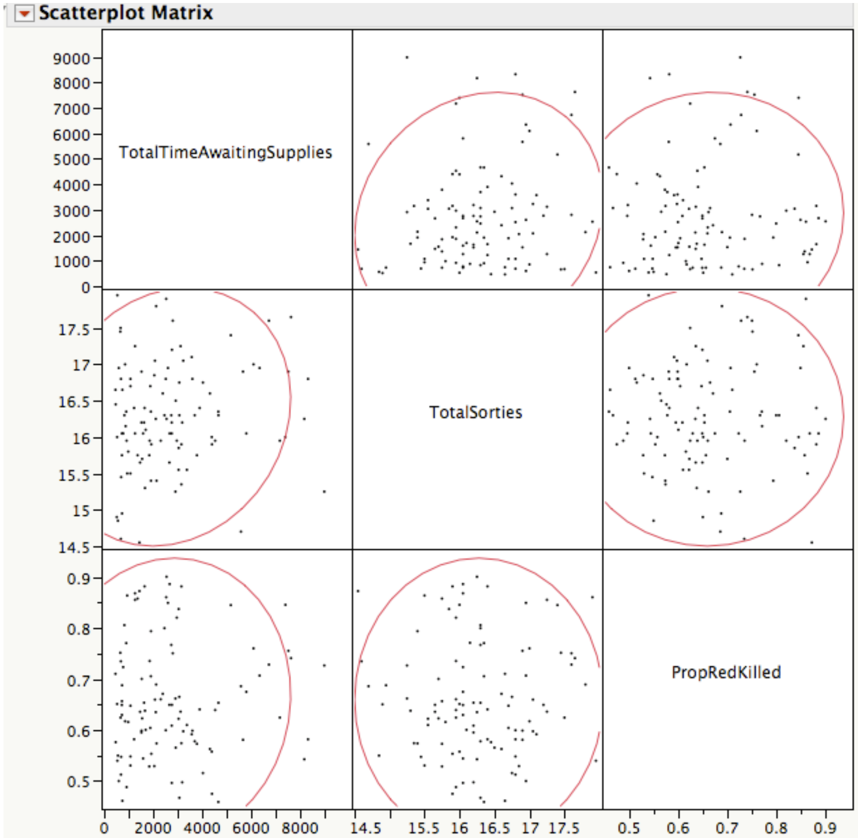
## A. DATA COLLECTION AND POST PROCESSING

One of the key advantages of using MANA is that it automatically produces output files for the desired MOEs. For each replication, MANA can also produce a set of "step" files which contain additional information about the run. For example, the "agentstates" step file includes the number of hits taken by each agent in the scenario, as well as the number of shots taken with each of an agent's weapons. After the set of runs for a study is complete, the "agentstates" files are collected and run through an Excel VBA script which loops through each of the files and computes the Total Time Awaiting Fuel and Total Sorties. These MOEs are then appended to the summary output file that MANA produces.

When the MANA experiment is combined with the SEED Center high-performance computing cluster, collecting the data is an automated process. When the experiment is complete, a single CSV file is generated containing variable factor input values and MOE output values. This CSV file is then imported into an analytical program like JMP or S-Plus. Once imported, the data are culled and arranged into a manageable table. Post-processing involves computing MOEs not directly reported by MANA. For example, the proportion of red agents killed is computed by dividing the number killed by the number the simulation started with for each design point. Other post-processing measures include "batching" the design point replications and/or other necessary steps for analysis. Batching refers to averaging the replication values over each design point. For example, this thesis ran the first experiment for 20 replications for each design point and a second experiment for 30 replications for each design point. The average of each design point parameter is batched and used for analysis. This technique helps to ensure the signal is seen through the noise in a stochastic model. The reader is directed to Alexopulos and Seila, 1998, for more information on batched means. Throughout the remainder of this chapter, this research uses JMP Statistical Discovery Software version 8.0.1 to conduct this analysis.

## B. MEASURES OF EFFECTIVENESS (MOE)

In any experiment, it is important to evaluate the correct performance measures to answer the questions at hand. This research uses three primary MOEs: proportion of enemy killed (the reader is reminded that red agents cannot kill blue agents—see Chapter II.F.4), total time awaiting supplies, and total sorties flown. To ensure all MOEs are measuring different aspects of the scenario, the scatter plot matrix in Figure 16 shows that strong linear relationships do not exist between them. The highest correlation, or measure of a linear relationship, is 0.14, so all three MOEs should be used to evaluate the questions above. Absolute correlation below 0.5 is generally considered a tolerable level of linear dependence for analysis (T. W. Lucas, personal communication, June 2010). The astute reader will notice that there are only 107 rather than 129 data points considered in Figure 16. This is explained in Section C of this chapter.




**Pairwise Correlations**

| Variable | by Variable | Correlation | Count | Lower 95% | Upper 95% | Signif Prob |
|---|---|---|---|---|---|---|
| TotalSorties | TotalTimeAwaitingSupplies | 0.1421 | 107 | -0.0491 | 0.3232 | 0.1443 |
| PropRedKilled | TotalTimeAwaitingSupplies | 0.0372 | 107 | -0.1537 | 0.2255 | 0.7033 |
| PropRedKilled | TotalSorties | 0.0008 | 107 | -0.1891 | 0.1906 | 0.9935 |

Figure 16. A scatter plot matrix of the measures of effectiveness.

### 1. Proportion of Enemy Killed

As previously discussed, this MOE is calculated to be the proportion of enemy that blue agents kill. When blue agents are in the "fuel out" state, meaning they have run out of supplies, they become combat ineffective and are not able to see or shoot red agents. The longer they are in this state, the better chance a red agent has of making it to its objective without being killed, so this MOE is used to evaluate the effectiveness of blue agent's ability to kill red agents. Other factors, like whether or not blue agents are mounted on vehicles, may also impact this MOE. This proportion may be presented as a percentage for readability.

### 2. Total Time Awaiting Supplies

This MOE is used to evaluate the MEU's ability to keep the company supplied. When a blue agent goes into a "fuel out" state, it returns to the base supply tank for a resupply. If the supply tank is empty, the blue agent shoots a secondary "counter" weapon once each second until it receives supplies. MANA tracks this MOE by summing the number of rounds each agent shoots over the simulation, so this MOE is the total number of seconds all blue agents had to wait on supplies. Because each second of simulation time computes to 30 seconds of real time, this figure could be multiplied by 30 to reflect the real time (in seconds) that all blue agents were out of fuel. However, since this is a linear transformation, it has no impact on the analysis, so the numbers are left as MANA reports them. What is important in this abstraction is the total waiting time; obviously, less is better.

### 3. Total Sorties Flown

This MOE is used to evaluate the demand the company places on the MEU's resources. Aircraft have a secondary counter weapon that shoots a single shot at a dummy agent (that only it can see) each time it flies a mission, so MANA can track the total number of sorties.

## C. ANALYSIS OF EXPERIMENT OUTPUT

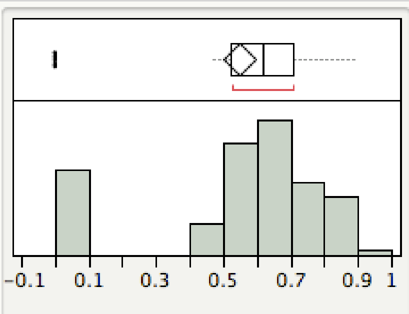
This section conducts a top-down analysis of the MANA output, primarily using partition trees and a multiple regression model to evaluate the MOEs. Partition trees are a nonparametric method for evaluating relationships between input variables and the response variable. One advantage of partition trees is their relatively intuitive format, coupling high explanatory power with ease of communication. The data starts out in one grouping and is iteratively "split" into groups that have different means with lower standard deviations than the group had before the split. This has the effect of increasing the $R^2$, a measure of how much variability in the data is explained by the model. Each split produces more "branches," or smaller groups in the tree, and should increase the $R^2$. The reader is directed to Kleijnen, Sanchez, Lucas, and Cioppa, 2005 for more information on partition trees.

Because MANA is a distillation model, for this analysis, the specific values for the partition tree splits or the regression model coefficients do not necessarily matter as much as the overall importance the input variables have in the model and the understanding they provide. This section starts with a basic statistical summary of the MOEs and then discusses several models based on the experiment's output.

### 1. Data Summary

The first MOE this section considers is proportion of enemy killed. Using the batched 129-design-point data, a simple distribution plot of this MOE (see Figure 17) actually reveals a modeling error. It should be nearly impossible that zero enemies are killed; however, the plot shows that it occurs in 22 of the 129 cases, or 17% of the time. Further investigation revealed that the "red movement speed in contact state" factor was entered into the design file incorrectly. The original design called for red agents to move at a constant default rate of 5 kph until they made contact with blue agents. In the contact states, the speed should have been varied from 0 to 5 kph to affect combat intensity. Instead of varying the red agent speed only when in contact with blue, the default speed was also varied from 0 to 5 kph throughout all states in the simulation. This means when the speed was set to 0, the red agents did not move towards their waypoints, so they never had a chance to be killed by blue agents. Fortunately, the NOLH design's robustness allows for continued analysis. Here, and in subsequent pages, graphs are presented as screen shots from JMP.

PropRedKilled




Quantiles

| | | |
|---|---|---|
| 100.0% | maximum | 0.90063 |
| 99.5% | | 0.90063 |
| 97.5% | | 0.88173 |
| 90.0% | | 0.845 |
| 75.0% | quartile | 0.70828 |
| 50.0% | median | 0.61688 |
| 25.0% | quartile | 0.5216 |
| 10.0% | | 0 |
| 2.5% | | 0 |
| 0.5% | | 0 |
| 0.0% | minimum | 0 |

Moments

| | |
|---|---|
| Mean | 0.5466909 |
| Std Dev | 0.2695035 |
| Std Err Mean | 0.0237285 |
| Upper 95% Mean | 0.5936417 |
| Lower 95% Mean | 0.4997401 |
| N | 129 |

Figure 17. The distribution of proportion of enemy killed using the 129-design-point data.

When the 22 0-kph cases are excluded from the data, 107 design points remain. An analysis of the factor distributions reveals a reasonably even spread among their ranges. Furthermore, the highest absolute pairwise correlation between the design points is 0.14, which is still acceptably low. The scatter-plot matrix in Figure 18 shows that the 107 design points are still sufficiently space filling. Because time constraints did not allow this experiment to be rerun, from this point forward, this thesis only discusses analysis of the 107 design point data, unless otherwise noted. The MOE distributions and summary statistics are found in Figure 19.

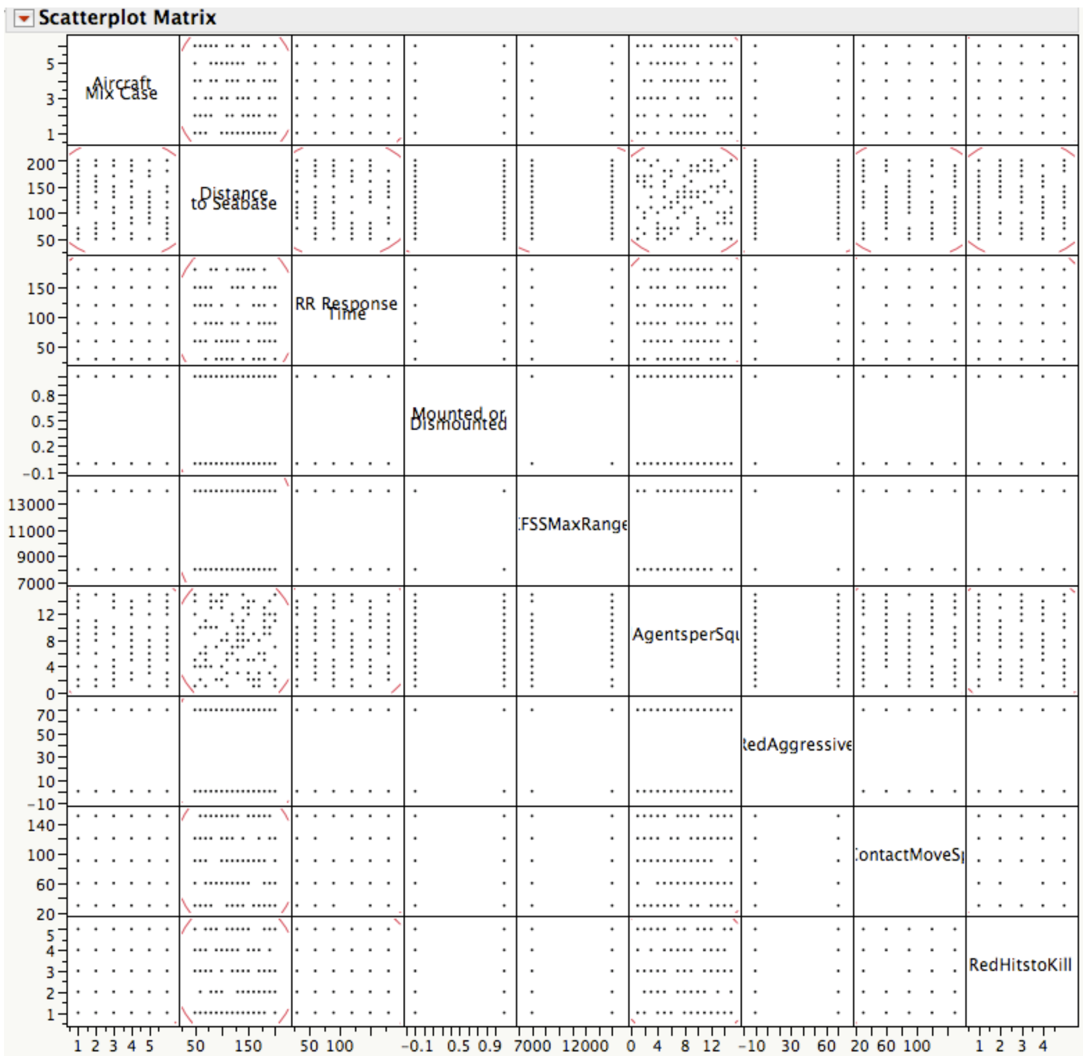



Figure 18. A scatter plot matrix of 107 design point data.

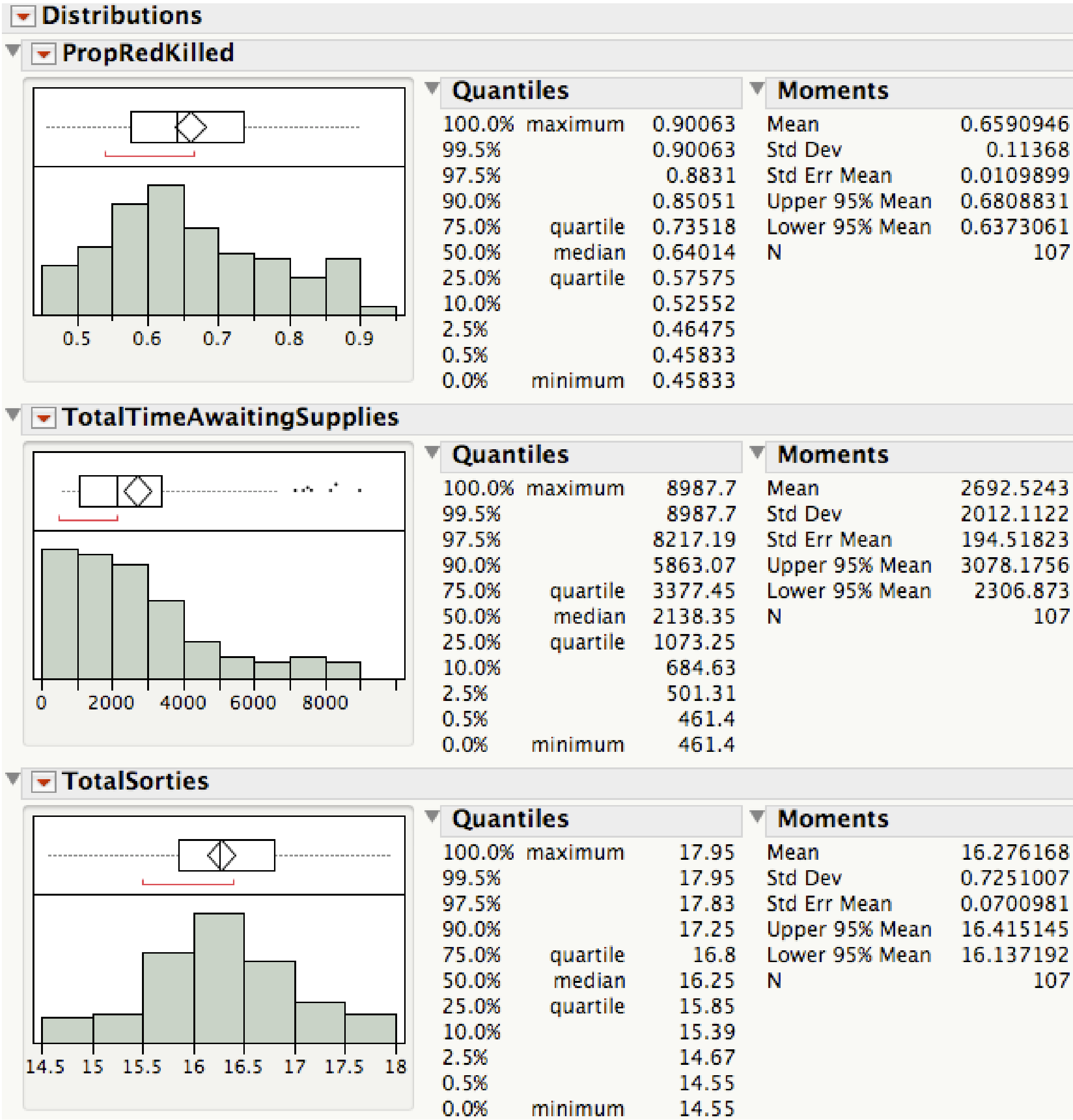



Figure 19. The MOE distributions and summary statistics.

### 2. Partition Trees

This section considers the insight provided by analyzing the MOE output using partition trees. The partition trees were built using the MOEs as the response variable and the nine design factors as the input variables.

#### *a. Proportion of Enemy Killed*

The first partition tree this research considers uses the proportion of red killed as the response. The first split, which explains 59% of the model variability, occurs when the red agent speed is less than two kph or greater than or equal to two kph. When the red agent speed is greater than two kph, which occurs in 21 of the 107 design points, the average proportion of red agents killed is approximately 83%. Otherwise, the proportion is approximately 62%. This finding simply indicates that slower red agents are easier to kill. The second split (see Figure 20) divides the two-kph-or-greater group in two, based on whether or not the blue agents were mounted on vehicles. When mounted (indicated by the number 1), the increased speed and weapons ranges make blue more efficient at killing red. Further branches of this tree reveal similar variations to this theme. These results may not be surprising, but it is nice when a model supports intuition. For this MOE, enemy speed and blue lethality dominate resupply factors.

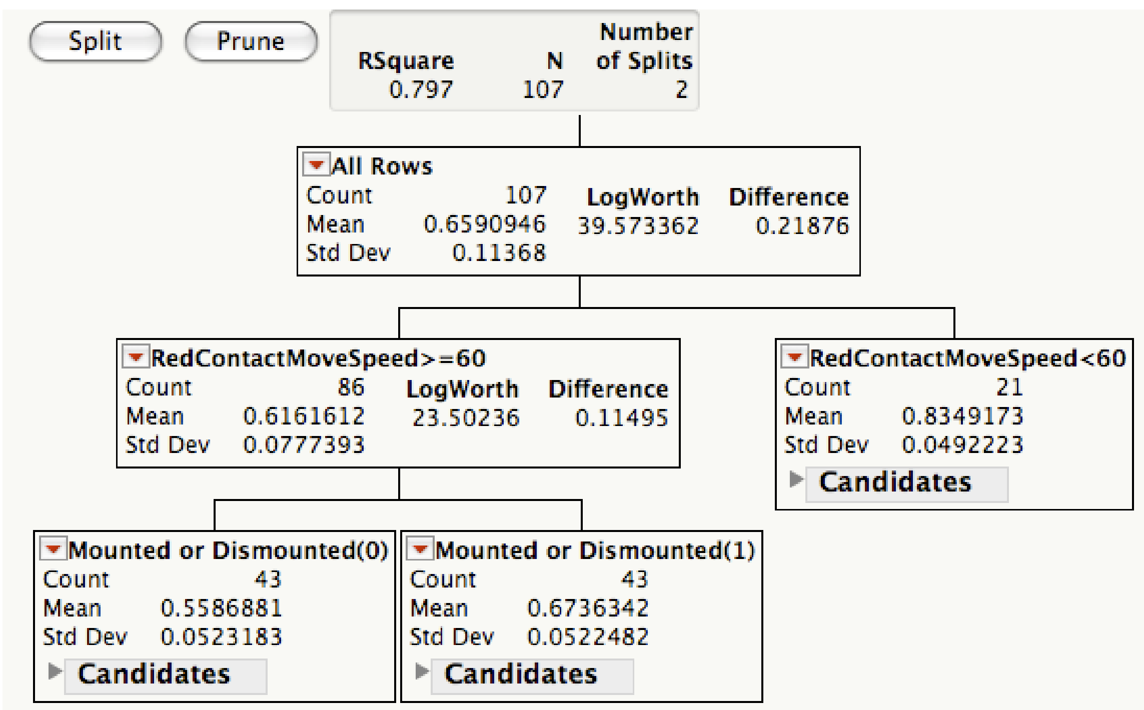



Figure 20. The proportion of red killed partition tree with two splits.

### *b. Total Time Awaiting Supplies*

The next MOE considered is total time awaiting supplies. One side benefit of the previously discussed modeling error is that there are 22 design points in which blue agents did not come into contact with red agents. This data provides a quasi-baseline of what the average time awaiting supplies would be without enemy contact. The distribution of these 22 design points is shown in Figure 21. The outlier is likely caused by that data point's parameters. It has the highest response time value, three hours, and it only has one CH-53, the slower helicopter, in its aircraft mix. Note that the average waiting time is significantly less than the average time found in Figure 19. It is also notable that both distributions have a high degree of variability.

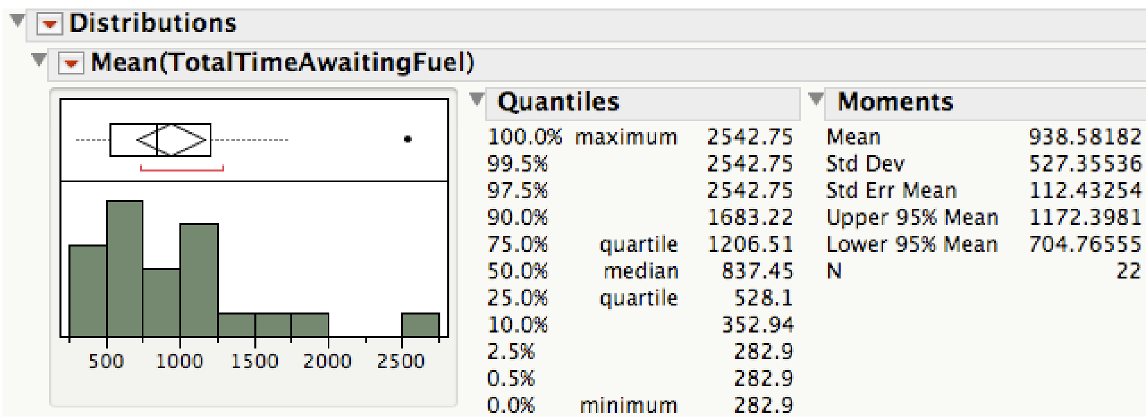



Figure 21. The distribution and summary statistics for total time awaiting fuel under the 22 design points that blue agents encountered no enemy contact.

Interestingly, the first split in partition trees for both cases is on rapid request response time. While it is not prudent to continue splitting the 22-point data because of the small number of data points, further splits of the 107-point data reveal this factor's importance. In fact, the first two splits, together accounting for approximately 53% of the model variability, are on rapid request response time. The first split is at 150 minutes, or 2.5 hours, and the second splits the less-than-150-minute branch at 90 minutes. The difference in means between these splits is substantial and can be seen in Figure 22. The longer the response time, the longer blue agents have to wait on supplies. The third split occurs when number of red agents per squad is either less than or greater than/equal to nine agents per squad. When there are nine or more, the blue agents wait longer for supplies because the combat intensity is higher. The fourth split is back to rapid request response time. All four splits can be seen in Figure 22. These last two splits only account for an additional 4% of the model variability. What is of note is what does not appear in the tree until the sixth split: distance to seabase. The response time dominates this factor because the distance to the seabase affects the wait due to travel time. Even in the most extreme case, when the seabase is 200 statute miles from the company, the slowest aircraft considered—the CH-53E—can still traverse that distance in approximately 70 minutes, which is easily dominated when compared to a 2-3 hour response time.

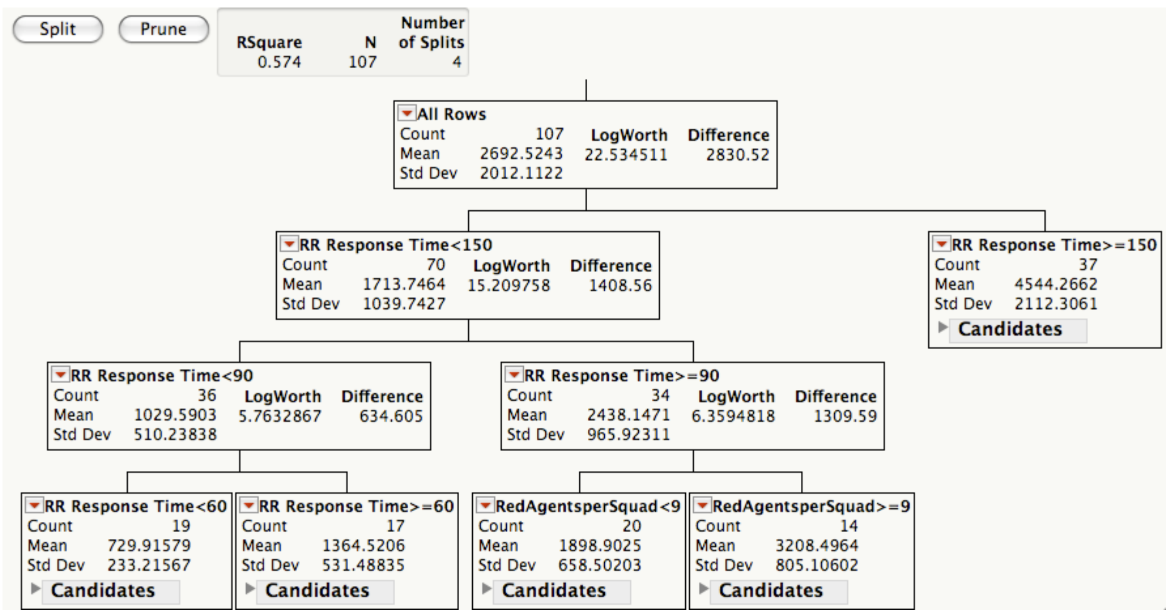



Figure 22. The partition tree at four splits for total time awaiting supplies using the 107-design-point data.

### *c. Total Sorties Flown*

The summary statistics in Figure 19 show the average total sorties flown to be approximately 16, with a relatively low standard deviation. The 22-point data with no enemy contact shows much the same thing. The partition tree for this MOE splits on noise factors until the fifth split where it spits on distance to seabase; however, the splits this deep in the tree are not explaining enough of the marginal model variability to be significant. It is likely that the number of sorties flown is relatively constant because this scenario only runs for 14 simulated days. Since the tanks only need to be supplied every three days or so, there are really only 4-5 opportunities for a tank to go empty, depending on combat intensity. When multiplied by three tanks in the model, the average of 16 total sorties is reasonable given the different aircraft mixes considered.

### 3. A Multiple Regression Model

Since the most interesting MOE appears to be total time awaiting supplies, this thesis considerers a multiple regression model run using mixed stepwise regression. The model was built using JMP's model builder tool, and all nine main effects, pairwise interactions, and second degree polynomial terms were considered. To avoid model over-fitting, the t-ratio p-values were set to less than 0.05 to enter and leave the model. This model's purpose is simply to divulge important factors and interactions. It is not intended to be used for prediction. Figure 23 shows the model coefficient estimates, and, more importantly, it shows that the model confirms the partition tree results that the rapid request response time dominates this MOE.

**Sorted Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| RR Response Time | 26.499959 | 1.506414 | 17.59 | <.0001* |
| Distance to Seabase | 8.4970943 | 1.610827 | 5.27 | <.0001* |
| RedAgentsperSquad | 91.192715 | 17.73178 | 5.14 | <.0001* |
| Aircraft Mix Case{5&3&4&1-6&2} | -428.4674 | 85.1793 | -5.03 | <.0001* |
| RedContactMoveSpeed | -7.464596 | 1.854322 | -4.03 | 0.0001* |
| (RedAgentsperSquad-7.91589)*(RedAgentsperSquad-7.91589) | -18.29675 | 4.669258 | -3.92 | 0.0002* |
| (RR Response Time-104.86)*(RedContactMoveSpeed-90.5607) | -0.139727 | 0.03636 | -3.84 | 0.0002* |
| (RR Response Time-104.86)*(RR Response Time-104.86) | 0.1158206 | 0.0355 | 3.26 | 0.0016* |
| (RR Response Time-104.86)*(RedAgentsperSquad-7.91589) | 1.1411 | 0.3507 | 3.25 | 0.0016* |
| Mounted or Dismounted[0] | 229.84079 | 77.68065 | 2.96 | 0.0039* |
| (Aircraft Mix Case{5&3&4&1-6&2}-0.36449)*(RedAgentsperSquad-7.91589) | -59.85825 | 20.45733 | -2.93 | 0.0043* |
| Aircraft Mix Case{4-1} | -371.2259 | 131.6436 | -2.82 | 0.0059* |
| (RedAgentsperSquad-7.91589)*(RedContactMoveSpeed-90.5607) | -1.109198 | 0.43652 | -2.54 | 0.0127* |
| (RR Response Time-104.86)*Mounted or Dismounted[0] | 3.5056226 | 1.516048 | 2.31 | 0.0230* |
| Aircraft Mix Case{5&3-4&1} | -178.0077 | 95.67955 | -1.86 | 0.0661 |

Figure 23. The total time awaiting supplies multiple regression model parameter estimates.

One parameter in the model deserves special note. The aircraft mix case category was split into two groups. One group contains aircraft mix cases 1, 3, 4, and 5, while the other contains cases 2 and 6. A check of Table 4 shows the difference between the cases to be the inclusion of the MV-22. Cases 2 and 6 do not include an MV-22, while the others do. Figure 24, which shows the interaction profiles for the factors that interact, indicates why this split is important. Each box in this figure has total time awaiting fuel on the y-axis and the factor in the column on the x-axis. The factor in the row divides the two lines in each box based on that row factor's high and low values. When the two lines are not parallel, an interaction between the row and column variable exists. An interaction is when the level of one variable positively or negatively affects the impact of the other variable on the response. For example, in the plot displayed in the first row, fourth column, there is an interaction between the aircraft mix case split and the number of red agents per squad. In general, the aircraft mix split with the MV-22 (the blue line) reduces the time blue agents wait on supplies, but this difference is less pronounced when there are fewer red agents per squad (i.e., when combat intensity is lower). The aircraft mix case split is due to the difference in speed between the MV-22 and CH-53E—240 nm per hour versus 150 nm per hour, respectively. When the MV-22 is not present in the aircraft mix, the blue agents must wait longer for the CH-53E to traverse the distance to the seabase. The importance of the MV-22 becomes even more apparent in the subexperiment discussed next.

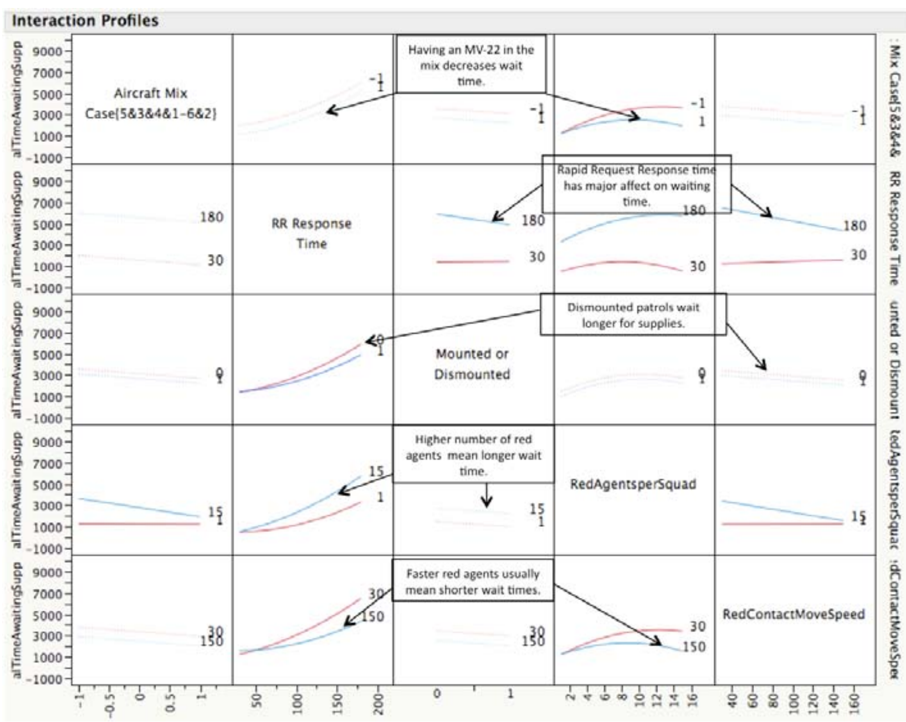
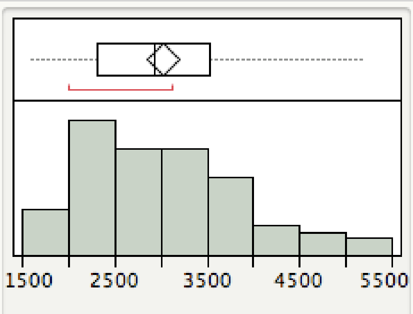



Figure 24. The total time awaiting supplies multiple regression model interaction profile plot [Best viewed in color].

#### 4. The Subexperiment

Since rapid request response time clearly dominated the total time awaiting supplies MOE, this thesis ran a subexperiment to further investigate the affect that distance to seabase and aircraft mix have on the model. In this experiment, only those two variables were changed. Since there are 16 possible levels of distance to seabase and only six possible aircraft mix combinations, this experiment used a full-factorial, 96-point design to evaluate every possible combination of factors. All other model variables were held constant at the levels indicated in Table 5. Thirty replications were done for each of the 96 design points, for a total of 2,880 simulated missions. These outputs were batched into their average values for analysis, just as was done in the first experiment. The distribution and summary statistics for the total time awaiting fuel using the subexperiment data is found in Figure 25. Note, that the model variability is much lower, as expected.

**Mean(TotalTimeAwaitingFuel)**




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 5211.83 |
| 99.5% | | 5211.83 |
| 97.5% | | 5146.82 |
| 90.0% | | 4331.8 |
| 75.0% | quartile | 3535.97 |
| 50.0% | median | 2928.23 |
| 25.0% | quartile | 2312.63 |
| 10.0% | | 2037.54 |
| 2.5% | | 1666.26 |
| 0.5% | | 1583.4 |
| 0.0% | minimum | 1583.4 |

**Moments**

| | |
|---|---|
| Mean | 3031.3215 |
| Std Dev | 865.17315 |
| Std Err Mean | 88.301365 |
| Upper 95% Mean | 3206.6219 |
| Lower 95% Mean | 2856.0212 |
| N | 96 |

Figure 25. The distribution and summary statistics for total time awaiting fuel using the subexperiment data.

Using a partition tree to evaluate the data, the first split is on aircraft mix case. This split divides cases 4 and 5 from cases 1, 2, 3, and 6. Another check of Table 4 indicates that the primary difference between these cases is the number of aircraft in the mix. Cases 4 and 5 each have three aircraft, but, more importantly, they each have two or more MV-22s, so the blue agents wait substantially less time for supplies. The next two splits are on the distance to the seabase. If there are two or more MV-22s in the mix, the split occurs at 130 miles; otherwise the split occurs at 110 miles. Interestingly, the average time awaiting supplies when the seabase is greater than or equal to 130 miles is still less than when it is less than the 110-mile distance, when there are one or fewer MV-22s in the mix. This comparison once again drives the point that the MV-22 provides a key advantage when supporting units from the seabase using a rapid request system. The fourth split divides the greater-than-or-equal-to-110 miles branch by aircraft mix. Once again the MV-22 cases (1 and 3) are separated from the CH-53E cases (2 and 6). Figure 26 shows the partition tree just discussed. The following chapter summarizes these results and draws the relevant conclusions this analysis provides.

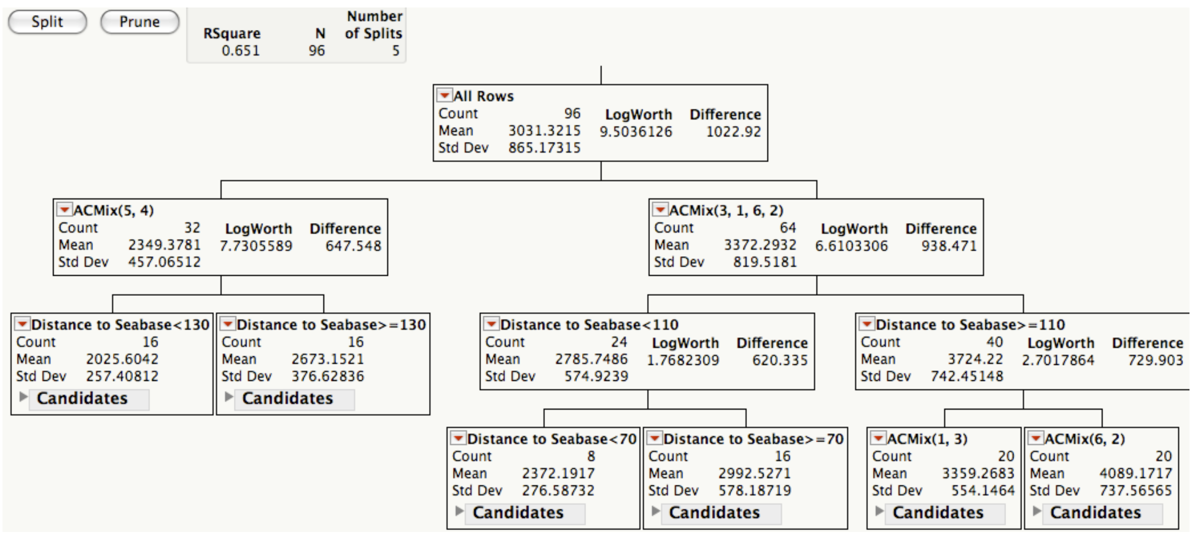



Figure 26. The partition tree at four splits for total time awaiting supplies using the 96-point subexperiment data.

# V. CONCLUSIONS

This research's purpose is to evaluate the affect that supporting an enhanced company would have on a MEU's logistical supporting assets. This chapter revisits the original research questions proposed in Chapter I and provides analytically-based insights that answer those questions.

## A. INSIGHTS INTO RESEARCH QUESTIONS

Recall from Chapter I that this research seeks to gain insight into four questions relating to the logistical supportability of an enhanced company, operating in an austere and hostile environment. They are directly answered here.

### 1. Given the current organizational structure of an MEU, what is the logistical impact of supporting an enhanced company with the MEU's supporting assets?

Most importantly, this research shows that it is possible to support an enhanced company using its current logistical assets under the assumptions of this scenario. While the logistical demand is approximated, the MEU's aircraft are capable of transporting the quantity of supplies an enhanced company is likely to consume. Additionally, the number of sorties required to support an enhanced company over a 2-week period remained relatively stable.

The key MOE, total time awaiting supplies, ranges from 461 to 8,988 time steps using a three-DOS rapid request model. Since this MOE is an aggregate of all 33 agents that demand supplies, it equates to a real-time range of 7 to 136 minutes per agent. For example, ((461 time steps aggregated wait time * 30 seconds/time step) ÷ 60 seconds/minute) ÷ 33 agents = 6.98 minutes per agent wait time. While it is not acceptable for a combat unit to ever run out of supplies, these figures come from a model that uses extreme ranges and a maximum of only three MEU aircraft, so they should be judged accordingly.

### 2. What are the critical logistical factors relating to mission success during ECO within the context of a given scenario?

The second experiment showed that the lowest average time awaiting supplies occurs when three aircraft, at least two of which being MV-22s, were used. Allocating one aircraft per platoon position yielded optimal results. Since increased combat intensity increased demand on MEU assets, this research also substantiates the need for reserve or surge capacity.

### 3. What are the critical logistical capabilities of the MEU that will enable it to provide continuous sustainment to an enhanced company?

This research reconfirms the logistical advantage the MV-22's speed and range provides. If all other parameters are equal, using MV-22s enable a seabase to be further away from the supported unit than using CH-53s, while still providing the same level of support. This simple fact validates the MV-22's contribution to the viability of the seabase concept.

### 4. What is the logistical impact of increasing the distance of the supported unit from the seabase?

As expected, increasing the supported unit's distance to the seabase increases wait time, but response time to rapid requests easily dominated this factor. The graph in Figure 27 illustrates this phenomenon. Logistical planners should work to minimize response time by taking steps such as building prepackaged supply bundles in anticipation of requests. This finding also provides a strong argument for incorporating scheduled resupply into the concept of support.

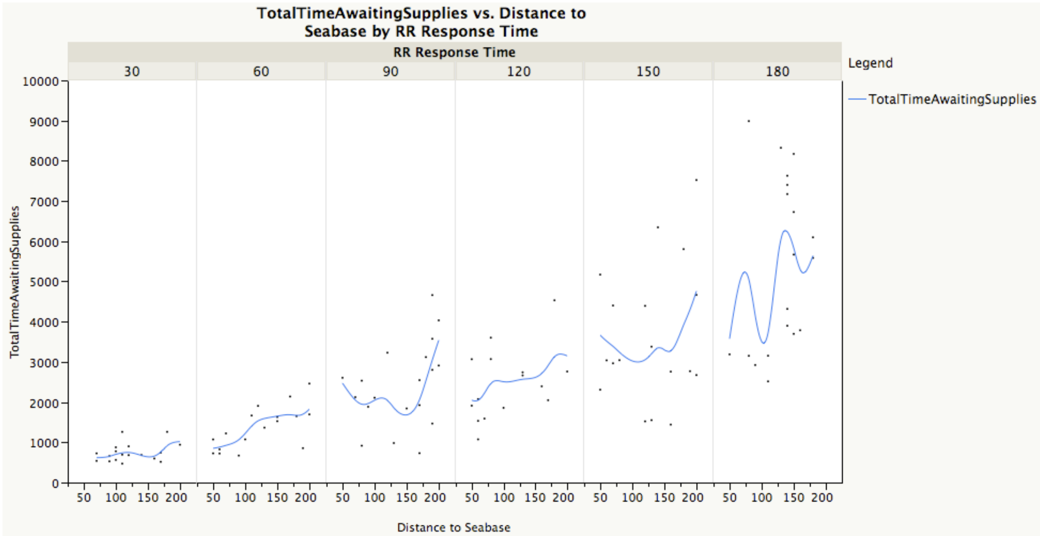



Figure 27. Total Time Awaiting Supplies versus Distance to Seabase by Rapid Request Response Time.

## B. FOLLOW-ON WORK

Due to time constraints, this research had to limit the number of simulated missions run on the SEED Center computer cluster. The modeling error discussed in Chapter IV should be corrected, and these experiments should be rerun, using both more design points and more replications per design point, to increase the statistical power of the analysis. Once these runs are complete, the analysis should be conducted once again to determine if more specific insight can be found.

The MANA model developed for this research can be adapted to explore many other questions. For example, it could be used to evaluate a scheduled resupply model, which could reveal that the CH-53's cargo capacity advantages trump the MV-22's speed advantage under that circumstance. This model could also be adapted to explore other aircraft options, like cargo unmanned aerial systems or C-130 air delivery capabilities, or other logistical requirements such as casualty evacuations.

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# APPENDIX A. SCENARIO TIME CONVERSIONS

This appendix contains the spreadsheets used to perform real-time conversions into MANA simulation time.

| Days in Scenario | Hours In Scenario | Minutes In Scenario | Minutes per Time Step | Total Time Steps in Scenario |
|---|---|---|---|---|
| 14 | 336 | 20160 | 0.5000 | 40320 |

| Time in Hours | MANA Time Steps |
|---|---|
| 0.5 | 60 |
| 1 | 120 |
| 1.5 | 180 |
| 2 | 240 |
| 2.5 | 300 |
| 3 | 360 |

| MV-22 Conversions @ 240 knot cruise speed | | | Total Rapid Request Response Delay (in time steps) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Distance in Miles | Flight Time in Sec. | Time Steps | 60 | 120 | 180 | 240 | 300 | 360 |
| 50 | 652 | 22 | 82 | 142 | 202 | 262 | 322 | 382 |
| 60 | 782 | 26 | 86 | 146 | 206 | 266 | 326 | 386 |
| 70 | 912 | 30 | 90 | 150 | 210 | 270 | 330 | 390 |
| 80 | 1043 | 35 | 95 | 155 | 215 | 275 | 335 | 395 |
| 90 | 1173 | 39 | 99 | 159 | 219 | 279 | 339 | 399 |
| 100 | 1303 | 43 | 103 | 163 | 223 | 283 | 343 | 403 |
| 110 | 1434 | 48 | 108 | 168 | 228 | 288 | 348 | 408 |
| 120 | 1564 | 52 | 112 | 172 | 232 | 292 | 352 | 412 |
| 130 | 1694 | 56 | 116 | 176 | 236 | 296 | 356 | 416 |
| 140 | 1825 | 61 | 121 | 181 | 241 | 301 | 361 | 421 |
| 150 | 1955 | 65 | 125 | 185 | 245 | 305 | 365 | 425 |
| 160 | 2085 | 70 | 130 | 190 | 250 | 310 | 370 | 430 |
| 170 | 2215 | 74 | 134 | 194 | 254 | 314 | 374 | 434 |
| 180 | 2346 | 78 | 138 | 198 | 258 | 318 | 378 | 438 |
| 190 | 2476 | 83 | 143 | 203 | 263 | 323 | 383 | 443 |
| 200 | 2606 | 87 | 147 | 207 | 267 | 327 | 387 | 447 |

| CH-53E Conversions @ 150 knot cruise speed | | | Rapid Request Response Delay (in time steps) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Distance in Miles | Flight Time in Sec. | Time Steps | 60 | 120 | 180 | 240 | 300 | 360 |
| 50 | 1043 | 35 | 95 | 155 | 215 | 275 | 335 | 395 |
| 60 | 1251 | 42 | 102 | 162 | 222 | 282 | 342 | 402 |
| 70 | 1460 | 49 | 109 | 169 | 229 | 289 | 349 | 409 |
| 80 | 1668 | 56 | 116 | 176 | 236 | 296 | 356 | 416 |
| 90 | 1877 | 63 | 123 | 183 | 243 | 303 | 363 | 423 |
| 100 | 2085 | 70 | 130 | 190 | 250 | 310 | 370 | 430 |
| 110 | 2294 | 76 | 136 | 196 | 256 | 316 | 376 | 436 |
| 120 | 2502 | 83 | 143 | 203 | 263 | 323 | 383 | 443 |
| 130 | 2711 | 90 | 150 | 210 | 270 | 330 | 390 | 450 |
| 140 | 2919 | 97 | 157 | 217 | 277 | 337 | 397 | 457 |
| 150 | 3128 | 104 | 164 | 224 | 284 | 344 | 404 | 464 |
| 160 | 3336 | 111 | 171 | 231 | 291 | 351 | 411 | 471 |
| 170 | 3545 | 118 | 178 | 238 | 298 | 358 | 418 | 478 |
| 180 | 3753 | 125 | 185 | 245 | 305 | 365 | 425 | 485 |
| 190 | 3962 | 132 | 192 | 252 | 312 | 372 | 432 | 492 |
| 200 | 4170 | 139 | 199 | 259 | 319 | 379 | 439 | 499 |

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# APPENDIX B.  SQUAD SPEED CONVERSIONS

This appendix contains the spreadsheet used to convert real-world speed into MANA agent speed.

| Squad Speed Conversions | | | |
|---|---|---|---|
| Real World kph | Meters/30 sec | Meters * 3600 time steps | MANA kph |
| 1 | 8.33 | 30000 | 30 |
| 2 | 16.67 | 60000 | 60 |
| 3 | 25.00 | 90000 | 90 |
| 4 | 33.33 | 120000 | 120 |
| 5 | 41.67 | 150000 | 150 |
| 56 | 466.67 | 1680000 | 1680 |

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# APPENDIX C. WEAPONS FIRING RATE CONVERSIONS

This appendix contains the spreadsheet used to calculate weapon firing rates in MANA simulation time.

| Weapon Specifications | | | | | | |
|---|---|---|---|---|---|---|
| **Weapon** | **Range (m)** | **Shot Radius (m)** | **Max Targets/ min** | **Max Targets/ step** | **Engagement/ sec** | **Engagement/ 30 sec** |
| M16A2 5.56mm Rifles | 550 | 1 | 12 | 6 | 0.20 | 6 |
| M203 Grenade Launcher | 350 | 5 | 7 | 3.5 | 0.12 | 3.5 |
| M249 SAW | 1000 | 1 | 85 | 42.5 | 1.42 | 42.5 |
| 60mm Mortars | 3500 | 27.5 | 20 | 10 | 0.33 | 10 |
| 81 mm Mortars | 5700 | 35 | 33 | 16.5 | 0.55 | 16.5 |
| .50 Cal MG | 1830 | 1 | 40 | 20 | 0.67 | 20 |
| M240G MG | 1800 | 1 | 100 | 50 | 1.67 | 50 |
| MK 14 Mod 3 MG | 1500 | 15 | 40 | 20 | 0.67 | 20 |
| EFSS 120mm Mortars | 8000 | 50 | 4 | 2 | 0.07 | 2 |
| Hand grenade | 40 | 15 | 6 | 3 | 0.10 | 3 |
| AK47 | 400 | 1 | 10 | 5 | 0.17 | 5 |
| RPG-7 | 500 | 1 | 6 | 3 | 0.10 | 3 |

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# APPENDIX D. MANA AGENT STATE TRACKER

This appendix contains a spreadsheet useful for tracking the agent state parameters in MANA.

| Patrolling Squad | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 1 | 3 | 3 | Patrol to next waypoint | 3 | 3 | |
| Fuel Out | 1 | 3 | 1 | Patrol back to base for resupply, shoot tank to count time in state | | | |
| Shot At | 1 | 3 | 1 | Refuel supplies | | | Default |
| En Contact 2 | 1 | 3 | 3 | Engage Red, use supplies twice as fast | 3 | 3 | Default |
| Sqd Shot At (Sec) | 1 | 3 | 3 | Engage Red, use supplies three time as fast | 3 | 3 | Default |

| Security Squad/Co HQ Squad | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 1 | 3 | 3 | Provide security | 3 | 3 | |
| Fuel Out | 1 | 3 | 1 | Resupply at tank, shoot tank to count time in state | | | |
| Shot At | 1 | 3 | 1 | Refuel supplies | | | Default |
| En Contact 2 | 1 | 3 | 3 | Engage Red, use supplies twice as fast | 3 | 3 | Default |
| Sqd Shot At (Sec) | 1 | 3 | 3 | Engage Red, use supplies three time as fast | 3 | 3 | Default |

| 60mm Mortar Fire Team | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 1 | 3 | 3 | Provide Fire Support | 3 | 3 | |
| Fuel Out | 1 | 3 | 1 | Resupply at tank, shoot tank to count time in state | | | |
| Shot At | 1 | 3 | 1 | Refuel supplies | | | Default |
| En Contact 2 | 1 | 3 | 3 | Engage Red, use supplies twice as fast | 3 | 3 | Default |
| Sqd Shot At (Sec) | 1 | 3 | 3 | Engage Red, use supplies three time as fast | 3 | 3 | Default |

| EFSS 120mm Mortar Fire Team | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 1 | 3 | 3 | Provide Fire Support | 3 | 3 | |
| Fuel Out | 1 | 3 | 1 | Resupply at tank, shoot tank to count time in state | | | |
| Shot At | 1 | 3 | 1 | Refuel supplies | | | Default |
| En Contact 2 | 1 | 3 | 3 | Engage Red, use supplies twice as fast | 3 | 3 | Default |
| Sqd Shot At (Sec) | 1 | 3 | 3 | Engage Red, use supplies three time as fast | 3 | 3 | Default |

| Supply Tank | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 2 | 1 | 1 | Wait for Blue agents to need refuel | 1 | 1 | |
| Ammo Out | 2 | 1 | 4, 5, or 6 | Wait to be resupplied by Aircraft | | | |
| Shot at (Pri) | 2 | 1 | 1 | Resupply tank | | | Default |

| MEU Aircraft | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 1 | 3 | 1 | Wait for supply tank to need refuel | 4, 5, or 6 | | |
| En Contact 1 | 1 | 3 | 1 | Transition to Spare 1 | 4, 5, or 6 | | Spare 1 |
| Spare 1 | 1 | 3 | 1 | Flight time delay from seabase to tank | | | Spare 2 |
| Spare 2 | 1 | 3 | 1 | Resupply (i.e. shoot) Tank | 4, 5, or 6 | 2 | Spare 3 |
| Spare 3 | 1 | 3 | 1 | Flight time delay from tank back to seabase | | | Default |

| Insurgent | | | | | | | |
|---|---|---|---|---|---|---|---|
| **State** | **Allegiance** | **Threat** | **Class** | **State Behavior** | **Sense** | **Shoot** | **Fall back to** |
| Default | 2 | 2 | 3 | Move to next waypoint | 3 | 3 | |
| En Contact 3 | 2 | 2 | 3 | Engage Blue, continue to next waypoint | 3 | 3 | Default |

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# APPENDIX E. PLANNING FACTOR DATA

This appendix contains the planning factor data this research uses. The Operations Analysis Division, Marine Corps Combat Development Command, Quantico, Virginia provided this data to the author in November 2009.

**Data Sources for Planning Factors**

**CLASS 1, WATER (potable and non-potable by environment)**

**Source:** Overarching Tactical Wheeled Vehicle Study 2001 recommended 7.0 gallons /Marine/day
**Number utilized was 7.0 gallons/Marine/day**

**CLASS 1, Rations (depends on mix and day)**

**Source:** Overarching Tactical Wheeled Vehicle Study 2001 recommended 5.25 lbs/Marine/day
This number modified to encompass weights of new MREs (1.86 lbs each instead of 1.75 lbs)
**Number utilized was 5.58 lbs/Marine/day (3 MREs @ 1.86 lbs each)**

**CLASS 2, (Clothing, Individual Equipment) Need CARF!**

**Source:** MAGTF Planner's Manual Feb 2009
No current CARF available!
**Utilized SWA number of 2.091 lbs/Marine/day**
**Number will need to be increased to 4.038 if Chemical defense is to be included**

**CLASS 3, Fuel**

**Source:** Overarching Tactical Wheeled Vehicle Study 2001
Continued current methodology of computing comsumption by TAMCN by gallons per hour and varying hours of operation based on Assault/Sustained Rate.

**CLASS 3, Lubricants**

**Source:** Most sources do not include any factor for lubricants
**Recommended further research**

**CLASS 4, (Construction) Need CARF!**

**Source:** MAGTF Planner's Manual Feb 2009
**Number utilized was 3.80 lbs/Marine/day**

**CLASS 5, Ammunition**

**Source:** MCO 8010.1E
Continue current methodology involving MCO 8010.1E (POM-10 Ammo PF) by DODIC
**Utilized current methodology**

**CLASS 6, Personal Demand Items**

**Source:** MAGTF Planner's Manual Feb 2009
**Number utilized was MAGTF Planner's Manual 2009 "Arid" number of 3.4 lbs/Marine/day**

**CLASS 7, (Major End Items) Need CARF!**

**Source:** Most sources have no factor for major end items.
**Continued current methodology of not including a planning factor for this class of supply**

**CLASS 8, AMALs and ADALs**

**Source:** MAGTF Planner's Manual 2009
**Number utilized was MAGTF Planner's Manual SWA number of 1.47 lbs/Marine/day**

**CLASS 9, Repair Parts**

**Source:** List from SMU
Currently utilizing 2.5 lbs/Marine/day but recommened get a current list of "mount out" repair items from the Sassy Management Unit (SMU)
**Utilizing 2.5 lbs/Marine/day until can get list from SMU**

**CLASS 2, Batteries (NEW!)**

**Source:** Software Power Version 1.3, from SYSDCOM which they received from US Army CECOM LCMC, Power Sources Team, dtd 10/03/2008
Current methodology utilizes current T/E for MEB units. Attempted to find each TAMCN from T/E in the Power Version 1.3 software
Those in the software were identified by type and number of batteries utilized. Then took the number of batteries, the hours of duration
for each type battery, and the weight of each battery to determine the total weight for batteries required in a day.
Finally, divided the total weight of batteries by the number of Marines in MEB to get requirement for batteries in lbs/Marine/day
**Utilized 5.417 lbs/Marine/day as initial number for new methodology.**

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# APPENDIX F. 129-FACTOR DESIGN OF EXPERIMENT TABLE

| Aircraft Mix Cat. | Dist to Seabase (Miles) | EFSS Max Range (Meters) | RR Response Time (Mins) | Mounted or not (binary) | # Red per Squad | Red Speed in Contact States (kph) | # Hits to kill Red | Red Aggressiveness (binary) |
|---|---|---|---|---|---|---|---|---|
| 2 | 120 | 8000 | 90 | 1 | 11 | 3 | 4 | 70 |
| 6 | 90 | 8000 | 90 | 1 | 7 | 2 | 2 | 0 |
| 3 | 170 | 8000 | 60 | 1 | 3 | 4 | 4 | 70 |
| 5 | 190 | 8000 | 90 | 1 | 12 | 0 | 3 | 0 |
| 1 | 110 | 14000 | 60 | 1 | 8 | 2 | 5 | 70 |
| 5 | 110 | 14000 | 30 | 1 | 5 | 3 | 1 | 0 |
| 3 | 200 | 14000 | 60 | 1 | 4 | 1 | 5 | 70 |
| 4 | 160 | 14000 | 30 | 1 | 14 | 5 | 1 | 0 |
| 1 | 50 | 8000 | 60 | 1 | 15 | 4 | 3 | 70 |
| 6 | 60 | 8000 | 60 | 1 | 2 | 1 | 3 | 0 |
| 1 | 200 | 8000 | 60 | 1 | 2 | 4 | 2 | 70 |
| 6 | 200 | 8000 | 90 | 1 | 15 | 3 | 5 | 0 |
| 3 | 90 | 14000 | 60 | 1 | 11 | 0 | 2 | 70 |
| 5 | 80 | 14000 | 90 | 1 | 4 | 5 | 3 | 0 |
| 2 | 130 | 14000 | 60 | 1 | 4 | 0 | 1 | 70 |
| 5 | 170 | 14000 | 30 | 1 | 8 | 5 | 4 | 0 |
| 2 | 70 | 8000 | 150 | 1 | 11 | 4 | 3 | 0 |
| 6 | 100 | 8000 | 150 | 1 | 3 | 0 | 3 | 70 |
| 2 | 170 | 8000 | 120 | 1 | 1 | 4 | 3 | 0 |
| 4 | 200 | 8000 | 150 | 1 | 12 | 2 | 1 | 70 |
| 2 | 80 | 14000 | 180 | 1 | 10 | 1 | 5 | 0 |
| 4 | 90 | 14000 | 180 | 1 | 2 | 5 | 2 | 70 |
| 2 | 160 | 14000 | 180 | 1 | 6 | 0 | 5 | 0 |
| 5 | 140 | 14000 | 180 | 1 | 10 | 4 | 2 | 70 |

| Aircraft Mix Cat. | Dist to Seabase (Miles) | EFSS Max Range (Meters) | RR Response Time (Mins) | Mounted or not (binary) | # Red per Squad | Red Speed in Contact States (kph) | # Hits to kill Red | Red Aggressiveness (binary) |
|---|---|---|---|---|---|---|---|---|
| 2 | 80 | 8000 | 120 | 1 | 15 | 2 | 2 | 0 |
| 6 | 50 | 8000 | 120 | 1 | 5 | 2 | 5 | 70 |
| 2 | 160 | 8000 | 180 | 1 | 2 | 3 | 2 | 0 |
| 6 | 200 | 8000 | 150 | 1 | 12 | 1 | 3 | 70 |
| 2 | 120 | 14000 | 120 | 1 | 9 | 0 | 2 | 0 |
| 4 | 120 | 14000 | 150 | 1 | 7 | 4 | 5 | 70 |
| 3 | 160 | 14000 | 150 | 1 | 6 | 0 | 1 | 0 |
| 4 | 150 | 14000 | 180 | 1 | 12 | 3 | 4 | 70 |
| 1 | 100 | 8000 | 90 | 2 | 8 | 5 | 3 | 70 |
| 6 | 120 | 8000 | 30 | 2 | 6 | 2 | 1 | 0 |
| 3 | 190 | 8000 | 90 | 2 | 3 | 5 | 5 | 70 |
| 4 | 180 | 8000 | 90 | 2 | 15 | 0 | 1 | 0 |
| 1 | 100 | 14000 | 30 | 2 | 13 | 2 | 4 | 70 |
| 6 | 70 | 14000 | 90 | 2 | 5 | 3 | 4 | 0 |
| 2 | 200 | 14000 | 30 | 2 | 1 | 1 | 5 | 70 |
| 6 | 180 | 14000 | 90 | 2 | 13 | 5 | 2 | 0 |
| 2 | 120 | 8000 | 60 | 2 | 11 | 3 | 1 | 70 |
| 5 | 110 | 8000 | 30 | 2 | 8 | 0 | 4 | 0 |
| 3 | 150 | 8000 | 60 | 2 | 5 | 5 | 1 | 70 |
| 4 | 180 | 8000 | 30 | 2 | 12 | 1 | 5 | 0 |
| 2 | 50 | 14000 | 90 | 2 | 9 | 1 | 3 | 70 |
| 6 | 110 | 14000 | 30 | 2 | 1 | 3 | 4 | 0 |
| 1 | 170 | 14000 | 90 | 2 | 2 | 1 | 1 | 70 |
| 4 | 190 | 14000 | 60 | 2 | 12 | 4 | 5 | 0 |

| Aircraft Mix Cat. | Dist to Seabase (Miles) | EFSS Max Range (Meters) | RR Response Time (Mins) | Mounted or not (binary) | # Red per Squad | Red Speed in Contact States (kph) | # Hits to kill Red | Red Aggressiveness (binary) |
|---|---|---|---|---|---|---|---|---|
| 3 | 110 | 8000 | 180 | 2 | 15 | 5 | 5 | 0 |
| 5 | 60 | 8000 | 120 | 2 | 7 | 0 | 2 | 70 |
| 3 | 130 | 8000 | 150 | 2 | 3 | 5 | 3 | 0 |
| 6 | 180 | 8000 | 180 | 2 | 9 | 2 | 2 | 70 |
| 2 | 80 | 14000 | 120 | 2 | 13 | 0 | 4 | 0 |
| 6 | 60 | 14000 | 120 | 2 | 2 | 3 | 2 | 70 |
| 2 | 160 | 14000 | 150 | 2 | 1 | 1 | 4 | 0 |
| 6 | 180 | 14000 | 150 | 2 | 10 | 3 | 2 | 70 |
| 1 | 60 | 8000 | 150 | 2 | 10 | 5 | 1 | 0 |
| 4 | 110 | 8000 | 180 | 2 | 3 | 1 | 5 | 70 |
| 1 | 180 | 8000 | 180 | 2 | 6 | 3 | 1 | 0 |
| 4 | 150 | 8000 | 180 | 2 | 14 | 2 | 4 | 70 |
| 3 | 100 | 14000 | 120 | 2 | 14 | 2 | 1 | 70 |
| 4 | 60 | 14000 | 120 | 2 | 6 | 4 | 4 | 70 |
| 3 | 140 | 14000 | 180 | 2 | 7 | 1 | 2 | 0 |
| 6 | 140 | 14000 | 180 | 2 | 9 | 4 | 3 | 70 |
| 4 | 130 | 14000 | 120 | 2 | 8 | 3 | 3 | 70 |
| 5 | 130 | 14000 | 120 | 2 | 5 | 2 | 2 | 0 |
| 1 | 160 | 14000 | 120 | 2 | 9 | 3 | 4 | 70 |
| 4 | 80 | 14000 | 150 | 2 | 13 | 1 | 2 | 0 |
| 2 | 60 | 14000 | 120 | 2 | 4 | 5 | 3 | 70 |
| 6 | 140 | 8000 | 150 | 2 | 8 | 3 | 1 | 0 |
| 2 | 140 | 8000 | 180 | 2 | 11 | 2 | 5 | 70 |
| 4 | 50 | 8000 | 150 | 2 | 12 | 4 | 1 | 0 |

| Aircraft Mix Cat. | Dist to Seabase (Miles) | EFSS Max Range (Meters) | RR Response Time (Mins) | Mounted or not (binary) | # Red per Squad | Red Speed in Contact States (kph) | # Hits to kill Red | Red Aggressiveness (binary) |
|---|---|---|---|---|---|---|---|---|
| 3 | 90 | 8000 | 180 | 2 | 2 | 0 | 5 | 70 |
| 6 | 200 | 14000 | 150 | 2 | 1 | 1 | 3 | 0 |
| 1 | 190 | 14000 | 150 | 2 | 14 | 4 | 3 | 70 |
| 6 | 50 | 14000 | 150 | 2 | 14 | 1 | 4 | 0 |
| 1 | 50 | 14000 | 120 | 2 | 1 | 2 | 1 | 70 |
| 4 | 160 | 8000 | 150 | 2 | 5 | 5 | 4 | 0 |
| 2 | 170 | 8000 | 120 | 2 | 12 | 0 | 3 | 70 |
| 5 | 120 | 8000 | 150 | 2 | 12 | 5 | 5 | 0 |
| 2 | 90 | 8000 | 180 | 2 | 8 | 0 | 2 | 70 |
| 5 | 180 | 14000 | 60 | 2 | 5 | 1 | 3 | 70 |
| 1 | 150 | 14000 | 60 | 2 | 13 | 5 | 3 | 0 |
| 5 | 80 | 14000 | 90 | 2 | 15 | 1 | 3 | 70 |
| 3 | 50 | 14000 | 60 | 2 | 4 | 3 | 5 | 0 |
| 5 | 170 | 8000 | 30 | 2 | 6 | 4 | 1 | 70 |
| 3 | 160 | 8000 | 30 | 2 | 14 | 0 | 4 | 0 |
| 5 | 90 | 8000 | 30 | 2 | 10 | 5 | 1 | 70 |
| 2 | 110 | 8000 | 30 | 2 | 6 | 1 | 4 | 0 |
| 5 | 170 | 14000 | 90 | 2 | 1 | 3 | 4 | 70 |
| 1 | 200 | 14000 | 90 | 2 | 11 | 3 | 1 | 0 |
| 5 | 90 | 14000 | 30 | 2 | 14 | 2 | 4 | 70 |
| 1 | 60 | 14000 | 60 | 2 | 4 | 4 | 3 | 0 |
| 5 | 130 | 8000 | 90 | 2 | 7 | 5 | 4 | 70 |
| 3 | 130 | 8000 | 60 | 2 | 9 | 1 | 1 | 0 |
| 4 | 90 | 8000 | 60 | 2 | 10 | 5 | 5 | 70 |

| Aircraft Mix Cat. | Dist to Seabase (Miles) | EFSS Max Range (Meters) | RR Response Time (Mins) | Mounted or not (binary) | # Red per Squad | Red Speed in Contact States (kph) | # Hits to kill Red | Red Aggressiveness (binary) |
|---|---|---|---|---|---|---|---|---|
| 3 | 100 | 8000 | 30 | 2 | 4 | 2 | 2 | 0 |
| 6 | 150 | 14000 | 120 | 1 | 8 | 0 | 3 | 0 |
| 1 | 130 | 14000 | 180 | 1 | 10 | 3 | 5 | 70 |
| 4 | 60 | 14000 | 120 | 1 | 13 | 0 | 1 | 0 |
| 3 | 70 | 14000 | 120 | 1 | 1 | 5 | 5 | 70 |
| 6 | 150 | 8000 | 180 | 1 | 3 | 3 | 2 | 0 |
| 1 | 180 | 8000 | 120 | 1 | 11 | 2 | 2 | 70 |
| 5 | 50 | 8000 | 180 | 1 | 15 | 4 | 1 | 0 |
| 1 | 70 | 8000 | 120 | 1 | 3 | 0 | 4 | 70 |
| 5 | 130 | 14000 | 150 | 1 | 5 | 2 | 5 | 0 |
| 2 | 150 | 14000 | 180 | 1 | 8 | 5 | 2 | 70 |
| 4 | 100 | 14000 | 150 | 1 | 11 | 0 | 5 | 0 |
| 3 | 80 | 14000 | 180 | 1 | 4 | 4 | 1 | 70 |
| 5 | 200 | 8000 | 120 | 1 | 7 | 4 | 3 | 0 |
| 1 | 140 | 8000 | 180 | 1 | 15 | 2 | 2 | 70 |
| 6 | 80 | 8000 | 120 | 1 | 14 | 4 | 5 | 0 |
| 3 | 70 | 8000 | 150 | 1 | 4 | 1 | 1 | 70 |
| 4 | 140 | 14000 | 30 | 1 | 1 | 0 | 1 | 70 |
| 2 | 190 | 14000 | 90 | 1 | 9 | 5 | 4 | 0 |
| 4 | 120 | 14000 | 60 | 1 | 13 | 0 | 3 | 70 |
| 1 | 70 | 14000 | 30 | 1 | 7 | 3 | 4 | 0 |
| 5 | 170 | 8000 | 90 | 1 | 3 | 5 | 2 | 70 |
| 1 | 190 | 8000 | 90 | 1 | 14 | 2 | 4 | 0 |
| 5 | 100 | 8000 | 60 | 1 | 15 | 4 | 2 | 70 |

| Aircraft Mix Cat. | Dist to Seabase (Miles) | EFSS Max Range (Meters) | RR Response Time (Mins) | Mounted or not (binary) | # Red per Squad | Red Speed in Contact States (kph) | # Hits to kill Red | Red Aggressivene ss (binary) |
|---|---|---|---|---|---|---|---|---|
| 1 | 70 | 8000 | 60 | 1 | 6 | 2 | 4 | 0 |
| 6 | 190 | 14000 | 60 | 1 | 6 | 0 | 5 | 70 |
| 3 | 140 | 14000 | 30 | 1 | 13 | 4 | 1 | 0 |
| 6 | 70 | 14000 | 30 | 1 | 10 | 2 | 5 | 70 |
| 3 | 100 | 14000 | 30 | 1 | 2 | 3 | 2 | 0 |
| 4 | 150 | 8000 | 90 | 1 | 2 | 3 | 5 | 0 |
| 3 | 190 | 8000 | 90 | 1 | 10 | 1 | 2 | 0 |
| 4 | 110 | 8000 | 30 | 1 | 9 | 4 | 4 | 70 |
| 1 | 120 | 8000 | 30 | 1 | 7 | 1 | 3 | 0 |

# APPENDIX G. 96-FACTOR DESIGN OF EXPERIMENT TABLE

| Aircraft Mix | Distance to Seabase (Miles) |
|---|---|
| 1 | 50 |
| | 60 |
| | 70 |
| | 80 |
| | 90 |
| | 100 |
| | 110 |
| | 120 |
| | 130 |
| | 140 |
| | 150 |
| | 160 |
| | 170 |
| | 180 |
| | 190 |
| | 200 |
| 2 | 50 |
| | 60 |
| | 70 |
| | 80 |
| | 90 |
| | 100 |
| | 110 |
| | 120 |
| | 130 |
| | 140 |
| | 150 |
| | 160 |
| | 170 |
| | 180 |
| | 190 |
| | 200 |

| **Aircraft Mix** | **Distance to Seabase (Miles)** |
|---|---|
| 3 | 50 |
| | 60 |
| | 70 |
| | 80 |
| | 90 |
| | 100 |
| | 110 |
| | 120 |
| | 130 |
| | 140 |
| | 150 |
| | 160 |
| | 170 |
| | 180 |
| | 190 |
| | 200 |
| 4 | 50 |
| | 60 |
| | 70 |
| | 80 |
| | 90 |
| | 100 |
| | 110 |
| | 120 |
| | 130 |
| | 140 |
| | 150 |
| | 160 |
| | 170 |
| | 180 |
| | 190 |
| | 200 |

| **Aircraft Mix** | **Distance to Seabase (Miles)** |
|---|---|
| 5 | 50 |
| | 60 |
| | 70 |
| | 80 |
| | 90 |
| | 100 |
| | 110 |
| | 120 |
| | 130 |
| | 140 |
| | 150 |
| | 160 |
| | 170 |
| | 180 |
| | 190 |
| | 200 |
| 6 | 50 |
| | 60 |
| | 70 |
| | 80 |
| | 90 |
| | 100 |
| | 110 |
| | 120 |
| | 130 |
| | 140 |
| | 150 |
| | 160 |
| | 170 |
| | 180 |
| | 190 |
| | 200 |

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# APPENDIX H. INTERNATIONAL DATA FARMING WORKSHOP 20 REPORT

## Team 1: The Logistical Impact of Marine Corps Enhanced Company Operations

### TEAM 1 MEMBERS

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### INTRODUCTION

The United States Marine Corps uses maneuver warfare as a basic doctrinal concept to fight its battles. Maneuver warfare demands the ability to avoid the enemy's strengths and attack his weaknesses in ways that are advantageous to the overall strategy. This overarching concept has heavily influenced the development of the Marine Air Ground Task Force (MAGTF)—a size-scalable, combined-arms, multi-mission-capable force used across the spectrum of conflict. The Marine Corps is continually developing tactics, techniques, procedures, and technologies that seek to increase the efficiency and lethality of the MAGTF. In this spirit, the Marine Corps Warfighting Laboratory (MCWL), whose "purpose is to improve current and future naval expeditionary warfare capabilities" (MCWL Website), is currently exploring the viability of a concept called Enhanced Company Operations (ECO).

In August 2008, the Commandant of the Marine Corps, General James Conway, signed a white paper entitled, "A Concept for Enhanced Company Operations," which states:

*Enhanced Company Operations describes an approach to the operational art that maximizes the tactical flexibility offered by true decentralized mission accomplishment, consistent with commander's intent and facilitated by improved command and control, intelligence, logistics, and fires capabilities. Enhanced Company Operations will be reliant on increased access to, and organic control of, functional support, as well as excellence at the individual, squad, and platoon levels. As such, it builds on the results of Distributed Operations experimentation and capability development to provide battalion commanders the critical link between operational planning and squad level tactical execution.*

ECO involves reorganizing and augmenting the traditional rifle company in a manner that contributes to "enhanced" $C^2$, intelligence, logistics, and fires capabilities. This process not only involves personnel changes, but also specific training and technological improvements. The end state is to develop the company's ability to become the base maneuver element of the MAGTF, a role traditionally held by the infantry battalion. Changes include the incorporation of a company-level operations center, a company-level intelligence capability, enhanced fire support coordination, and personnel specifically tasked to focus on logistics.

This team participated in an ongoing Naval Postgraduate School thesis project to explore the logistical impact of a deployed enhanced company on a Marine Expeditionary Unit's (MEU) supporting assets. At the start of the workshop, the team had the following goals:

1. Asses and refine a simulation model developed using Map-Aware Non-uniform Automata (MANA) to evaluate the logistical impact of Marine Corps Enhanced Company Operations on a Marine Expeditionary Unit.
2. Determine appropriate variables and ranges to incorporate into an experimental design.

The MANA model referred to above is centered on a realistic Africa-based scenario that allows enemy agents to influence the logistical demand of the supported company.

#### Description of Scenario

This study uses a scenario developed by MCWL and used during the ECO Fires Conference of 21-23 April 2009, which provides a realistic operational environment with which to test the ECO concept. The fictional scenario takes place on the African continent in the border area between Burundi and the Democratic Republic of the Congo. In the notional orders describing the scenario, MCWL changed the names of the countries to prevent others from mistaking them for real-world events.

The United States has a supportive relationship with the government of Bunduri, a relatively stable democracy in East Africa. The U.S. has a neutral relationship with the government of Razie, which is led by a corrupt president who has used various nefarious means to stay in power for many years. Within Razie, there is a government opposition movement called the Movement for Democratic Change (MDC). In the latest elections, the leader of the MDC won the popular vote, but the sitting president refused to recognize the election results. As a result of internal and international pressures, the two parties reached a power-sharing agreement with the president remaining in place and the winner of the elections serving as prime minister.

After a failed assassination attempt on the prime minister, in which the president's followers were implicated, the president dissolved the national government and instituted martial law. The prime minister fled to the east of Razie with his MDC followers. The MDC's military arm, the Manicaland Peoples Force (MPF), rebelled and took control over Manica Province in Eastern Razie. The former prime minister announced the formation of the independent state of Manicaland and declared war against Razie. Additionally, he declared Manica tribal lands within Bunduri as a part of Manicaland, and the MPF crossed into western Bunduri. The contested area is shown in Figure 1.

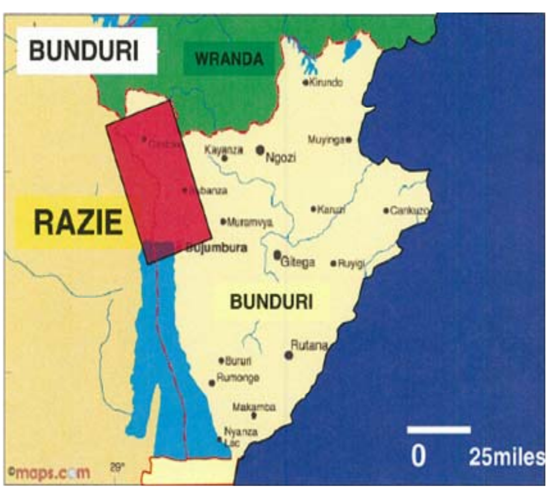


Figure 1: Scenario Area of Operations

The simulation attempts to model ECO-capable Alpha Company. MPF forces have been kicked out of Alpha Company's area of operations (AO), but they continue to make incursions across the border to influence the local populace and to harass friendly forces. Since Alpha Company is the main effort, they have the luxury of receiving the priority of support from the MEU's assets.

### The MANA Model

This team began the conference with an initial model representing Alpha company's AO already built in MANA version 5. A screen shot is shown in Figure 2.

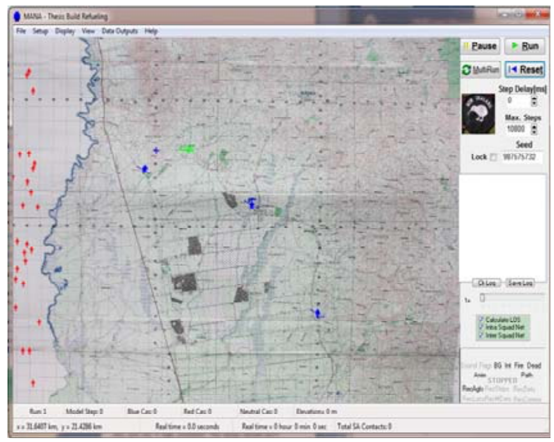


Figure 2: Screen shot of initial MANA model

The model background is a topographical map of the scenario area. The red agents start on the Razie side of the boarder (denoted by the blue river) and will attempt to make it to the right most side of the play board. Alpha Company has three established platoon positions within their AO. At each position, two squads run patrols, and one squad remains for security. There is also a 60mm mortar team at each platoon position. As the model runs, the patrolling blue agents will interdict the red agents when they come into sensor and weapons ranges.

## WORKSHOP RESULTS

The team spent the first day of the workshop familiarizing themselves with ECO, the scenario, and MANA.

The team spent the second day attempting to incorporate the scenario logistical aspects into MANA. Our original idea was to have a supply "tank" at each platoon position that would hold two days of supply units for each blue agent at that position. Each agent starts with one day of supply, and returns to the patrol base for a resupply when its tank is empty, so each agent has a total of three days of supply available at the start of the scenario. When the patrol base tank is depleted, a resupply agent, the MEU helicopter, flies to the tank and replenishes the supply units. We attempted to model this behavior using MANA's fuel parameter and auto-refueller agents.

The team had trouble implementing this scenario into MANA. Our initial attempt had the agents transition from their default state to a "fuel out" state when their resources were depleted, and then to a "refuel by friend" state when they come into contact with the resupply tank. Unfortunately, this did not give the desired behavior because as each squad entered the "fuel out" state, some of the agents would immediately transition into the "refuel by friend" state due to their close proximity to other friendly agents in the squad. This resulted in some agents transferring back to their default state without receiving any fuel, which then continued to decrement their fuel parameter below zero, causing the agent to never enter the "fuel out" state again. Many different combinations of triggers and trigger states were attempted in order to get this refueling scenario to work, but despite the large amount of experience with MANA no combination of triggers and trigger states produced the desired result. The team also had trouble with MANA's seemingly random handling of agents. For example, MANA would sometimes allow two agents to refuel from the tank during the same time step, but it would only deplete the tank one agent's allocation of supply units. By the end of the second day, we had decided to try another method.

The team spent day three creatively using MANA to create the desired logistical behavior. This time, instead of using MANA's refueling states, we relied on the different sensor and weapon parameters to trigger when an agent could refuel itself by using a negative fuel consumption rate. For instance, an agent starts patrolling with one day of supply units. Once those units are depleted, that agent changes to a state that is visible to the resupply tank's sensor and returns to the base. When the agent returns to the base, and comes within the resupply tank's weapon's range, it is shot by the tank. The agent switches into the "shot at" state, refuels itself, and then continues on its mission. When the tank has fired all of its ammunition, which is used to represent the tank's supply capacity, it changes states into one visible by the resupply agent (the MEU helicopter), is shot at by the resupply agent, and reverts back into the default state with a full load of ammunition (i.e. supplies).

While this algorithm worked in a simplified model, apparently random behavior in MANA stopped it from working in the more complicated scenario. Similar to our initial attempt, we experienced problems with the agent's transition between states. MANA appeared to have a problem with the state duration which, from time to time, would adjust itself by a single time step. One of the effects of this was that the agent spent too much or too little time in the "shot at" state and was not refueled accurately; agents often received too much or too little fuel. In another instance, the resupply tank would shoot the blue agents even though it was out of ammunition. Our conclusion was that unresolved issues and model limitations in the current release of MANA 5 made this model unsuitable for this particular study.

Although this team spent over 64 man hours trying to get MANA to work, all is not lost. After the conference, Capt Hinkson contacted one of the MANA developers, Mark Anderson, who explained that MANA uses a random draw to determine which agent gets to have its turn first. MANA also did not implement trigger state changes in the same time step in which they occurred. This explained MANA's apparently erratic behavior. Mr. Anderson provided Capt Hinkson with an updated version of MANA 5 that included instantaneous state changes. The model now appears to be working as desired.

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