NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

OPERATIONAL ENERGY/OPERATIONAL EFFECTIVENESS INVESTIGATION FOR SCALABLE MARINE EXPEDITIONARY BRIGADE FORCES IN CONTINGENCY RESPONSE SCENARIOS

by

Team Expeditionary
Cohort 311-132

December 2014

Project Advisors: Eugene P. Paulo
Brigitte T. Kwinn
Paul T. Beery
Raymond J. Madachy

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704–0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2014	**3. REPORT TYPE AND DATES COVERED** Capstone Project Report	
4. TITLE AND SUBTITLE OPERATIONAL ENERGY/OPERATIONAL EFFECTIVENESS INVESTIGATION FOR SCALABLE MARINE EXPEDITIONARY BRIGADE FORCES IN CONTINGENCY RESPONSE SCENARIOS			**5. FUNDING NUMBERS**
6. AUTHOR(S) Cohort 311-132/Team Expeditionary			
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**

13. ABSTRACT (maximum 200 words)

In today's austere fiscal environment the United States Marine Corps (USMC) seeks to increase overall mission effectiveness, while maintaining or improving combat effectiveness, through efficient energy use in the battle space. This capstone project examined operational energy efficiencies through the specification, modeling, and data analysis associated with force scale alternatives of a Special Purpose Marine Air Ground Task Force (SPMAGTF) unit operating in the West Africa Area of Responsibility (AOR). A Title 10 war games evolution was elaborated to support a robust operational concept. A Model Based Systems Engineering (MBSE) approach was utilized to support the Analysis of Alternatives (AoA). Agent Based Modeling and Simulation (ABMS) provided the foundation to explore autonomous battle space activity and its relationship to operational energy. Design of Experiments (DOE) principles were used to specify force scale levels suitable for examination of the tradespace. The research objectively sought to understand the relationship between force scale, energy use, and mission effectiveness. Results support findings regarding key energy drivers, energy dependencies across the combat elements of the battle space, economies of scale, and net-centricity. The findings inform evaluation of force application doctrine in small land battle engagements, and provide modeling artifacts for future research efforts.

14. SUBJECT TERMS Model based systems engineering, alternatives of analysis, design of experiments, agent based modeling and simulation; operational energy			**15. NUMBER OF PAGES** 357
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01-280-5500 Standard Form 298 (Rev. 2–89) Prescribed by ANSI Std. 239–18

THIS PAGE INTENTIONALLY LEFT BLANK

OPERATIONAL ENERGY/OPERATIONAL EFFECTIVENESS INVESTIGATION FOR SCALABLE MARINE EXPEDITIONARY BRIGADE FORCES IN CONTINGENCY RESPONSE SCENARIOS

Cohort 311-132/Team Expeditionary

Clayton Bennett
Hughlyn Henderson
Matthew Mussman
Christopher Farris
Stacy Himes
Michael Newman, PhD
Brandon Harwood
Paul Foxx
Corey Kennington
Maysam Sarfaraz

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 2014

Lead editor: Corey Kennington

Reviewed by: Eugene P. Paulo, PhD, Project Advisor
Brigitte T. Kwinn, Project Advisor
Paul T. Beery, Project Advisor
Raymond J. Madachy, PhD, Project Advisor

Accepted by: Cliff Whitcomb
Systems Engineering Department

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

In today's austere fiscal environment, the United States Marine Corps seeks to increase overall mission effectiveness, while maintaining or improving combat effectiveness, through efficient energy use in the battle space. This capstone project examined operational energy efficiencies through the specification, modeling, and data analysis associated with force scale alternatives of a Special Purpose Marine Air Ground Task Force unit operating in the West Africa area of responsibility. A Title 10 war games evolution was elaborated to support a robust operational concept. A model based systems engineering approach was utilized to support the analysis of alternatives. Agent based modeling and simulation provided the foundation to explore autonomous battle space activity and its relationship to operational energy. Design of experiments principles were used to specify force scale levels suitable for examination of the tradespace. The research objectively sought to understand the relationship between force scale, energy use, and mission effectiveness. Results support findings regarding key energy drivers, energy dependencies across the combat elements of the battle space, economies of scale, and net-centricity. The findings inform evaluation of force application doctrine in small-land battle engagements, and provide modeling artifacts for future research efforts.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	Anti-Access/Area-Denial
ABMS	Agent Based Modeling and Simulation
ACE	Aviation Command Element
AHP	Analytical Hierarchy Process
ANOVA	Analysis of Variance
AoA	Analysis of Alternatives
AOR	Area of Responsibility
APODS	Ariel Points of Debarkation
ASCM	Anti-Ship Cruise Missiles
BDA	Battle Damage Assessment
BN	Battalion
C2	Command and Control
C3	Command Control and Communication
CAAT	Combined Anti-Armor Team
CAS	Close Air Support
CCD	Charged-Couple Device
CDD	Capability Development Directorate
CE	Command Element
CJTF	Combined Joint Task Force
CO	Commanding Officer
COA	Course of Action
CONEMP	Concept of Employment
CONOPS	Concept of Operations
CSV	Comma Separated Value
DES	Discrete Event Simulation
DEV	Deviation
DOA	Days of Ammunition
DOD	Department of Defense

DOE	Design of Experiments
DOS	Days of Supplies
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities
DR	Disaster Relief
DTA	Defense Technology Agency
E2	Expeditionary Energy
E2O	Expeditionary Energy Office
EF	Expeditionary Force
EISA	Energy Independence and Security Act
EO	Executive Order
Err	Error
EW	Expeditionary Warrior
EW12	Expeditionary Warrior 2012
FHA	Foreign Humanitarian Assistance
FOB	Forward Operating Base
FSM	Free Savanna Movement
GCE	Ground Combat Element
GPMD	Gallons per Marine per Day
GUI	Graphical User Interface
HADR	Humanitarian Aid and Disaster Relief
HMG	Heavy Machine Gun
HMMWV	High Mobility Multi-purpose Wheeled Vehicles
HTK	Hits to Kill
IADS	Integrated Air Defense Systems
IMTV	Improved Modular Tactical Vests
IR	Infrared
LCAC	Landing Craft Air Cushion
LCE	Logistics Combat Element
LER	Loss Exchange Ratio

LOGMAT	Logistics and Material Supply
LSCR	Laundry, Shower, and Clothing Repair
LVSR	Logistics Vehicle System Replacement
LZ	Landing Zone
M&S	Modeling and Simulation
MADA	Multiple Attribute Decision Analysis
MAGTF	Marine Air-Ground Task Force
MANA	Map Aware Non-uniform Automata
MARCORSYSCOM	Marine Corps System Command
MATLAB	Matrix Laboratory
MB	Megabyte
MBSE	Model-Based Systems Engineering
MCDP	Marine Corps Doctrinal Publication
MCT	Marine Corps Task
MCTL	Marine Corps Task List
MCWL	Marine Corps Warfighting Laboratory
MEB	Marine Expeditionary Brigade
MEDEVAC	Medical Evacuation
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MG	Machine Gun
MOE	Measure of Effectiveness
MPEM	Marine Air-Ground Task Force Power and Energy Model
NDAA	National Defense Authorization Act
NPS	Naval Postgraduate School
OA	Objective Area
OE2	Operational Energy and Operational Effectiveness
OER	Operational Effectiveness Requirement
OMB	Office of Management and Budget
OMOE	Overall Measure of Effectiveness

ONR	Office of Naval Research
OPFOR	Opposing Force
OPS	Operations
PODS	Points of Debarkation
QRF	Quick Reaction Force
QTY	Quantity
RGB	Red, Green, and Blue
ROE	Rules of Engagement
S&T	Science and Technology
SA	Situational Awareness
SALUTE	Size, Activity, Location, Unit, Time, and Equipment
SAW	Squad Automatic Weapon
SBAs	Sea Based Assets
SCE	Sea Combat Element
SE	Systems Engineering
SECNAV	Secretary of the Navy
SEED	Simulation Experiments and Efficient Design
SPMAGTF	Special Purpose Marine Air Ground Task Force
SPODS	Sea Points of Debarkation
SSBM	Surface-to-Surface Ballistic Missiles
STD	Standard
TECCOM	Training and Education Command
TRADOC	US ARMY Training and Doctrine Command
TTP	Tactics, Techniques, and Procedures
U.N.	United Nations
U.S.	United States
USMC	United States Marine Corps
WAF	West African Federation

EXECUTIVE SUMMARY

This capstone project supported the United States Marine Corps (USMC) Expeditionary Energy Office (E2O) operational energy research objectives and provided a basis for Naval Postgraduate School (NPS) future research projects. Team Expeditionary recommends that the E2O examine artifacts of this capstone effort and assess options and priorities for continued pursuit of the operational energy topics contained herein. NPS should maintain the artifacts and examine the value of incorporating operational energy decision making into dashboard metrics. Future research investigations presented within this capstone report should be considered in terms of how they might facilitate objectives of both E2O and NPS. The team proposed four future research topics including holistic mission modeling to utilize the team's robust Concept of Operation (CONOP), incorporation of net-centricity in operational modeling, hybrid modeling to utilize multiple types of modeling paradigms, and behavioral modeling to examine decision making in scarce resource environments.

The results of the analysis in this capstone project addressed research questions regarding the application of operational force scale and related energy costs associated with the conduct of a successful USMC expeditionary mission. The mission included an Air Combat Element (ACE) providing maneuver insertion and combat support to a Ground Combat Element (GCE) pursuing a direct fires engagement. Analysis of the operational energy and mission effectiveness data supported four findings which are detailed as follows.

Key energy drivers were found to be largely determined by a combination of ACE support provided to the GCE and the overall force scale. Specific details were uncovered for variable energy drivers and fixed or pre-determined energy drivers. While the energy commitment for a ground fires mission seems to be made in advance, the prosecution of the battle also has a bearing on the energy use of the ACE supporting the ground battle.

The relationships of energy dependencies in the battle space were further detailed in the second finding of the study as follows. In terms of the mission context modeled,

this study found that both battle length and casualty rate were directly proportional to ACE energy requirements. Casualty rate determined the largest variable energy driver; and battle length determined the on-station time requirement for Close Air Support (CAS).

The third finding exposed the key relationship that increased force scale, improves the effectiveness of the direct fires mission, but increases have diminishing energy cost returns. This finding was supported by Loss Exchange Ratio (LER) analysis, examination of fires efficiency, injury rates, and the energy data (Darilek et al. 2001).

The fourth finding stated that superior weapons and armor do not necessarily compensate for an inadequate battle space understanding and this impacts energy. This finding was supported by the injury data and sensitivity analysis which showed that significant injuries were a cost associated with the battle of attrition demonstrated by the experiment.

Team Expeditionary implemented a Model Based Systems Engineering (MBSE) approach which facilitated discovery, iteration, and evaluation while the team pursued the research questions. The MBSE approach allowed the specification and construction of a predictive model, while subsequent execution of the predictive model allowed the study of trades between operational energy and operational effectiveness. (International Council on Systems Engineering (INCOSE) 2007) The following process steps were followed to implement the approach. The steps are further elaborated throughout this summary.

- Initial Research
- Refinement of Need
- Requirements Analysis
- Mission Analysis
- System Architecture
- Modeling and Simulation
- Analysis of Alternatives

Initial investigations identified stakeholders and USMC foundational documents which were ultimately used to align mission functionality to the Marines doctrine. The team reviewed two previous NPS expeditionary energy capstone reports which focused on early mission phases of Expeditionary Warrior 2012 (EW12), the Title 10 War Games evolution. These projects were used to gain an understanding of the mission context and methods previously used to implement the MBSE approach. Research questions for this capstone project considered energy costs of a successful expeditionary mission, the force scale relationship to operational energy and operational effectiveness, and the trajectory of the operational energy / operational effectiveness tradespace.

The preliminary need statement provided by NPS was analyzed and an effective need statement formed which balanced the precedence and preference of the stakeholders. The effective need required the team to use MBSE to address factors associated with the USMC successful expeditionary mission. The primary stakeholder value associated with the effective need was ultimately derived from exposing the relationship between operational energy and operational effectiveness. Additional value was derived from the extensibility of this research. Pursuant to extensible research the effective need elaborated details regarding the robustness of the mission context and relevance of Title 10 War Games evolutions.

Requirements were established to guide the specification of a notional system, the systems mission context, and the modeling required to conduct experimentation pursuant to the MBSE trade study. The notional system was required to be operationally effective, energy efficient, and scalable in accordance with USMC doctrinally established functional and physical architectures. As determined by scale, the system was required to support war fighting functionality including Maneuver, Intelligence, Fires, Logistics, Command & Control, and Force Protection. Additionally, the system must be able to be represented in an executable operational model to support data farming for the Analysis of Alternatives (AoA). The mission analysis must be robust enough to support the modeling in this capstone project and provide a foundation for future research.

The Mission analysis and operational concept development explored operation Restore Sovereignty; the West Africa based Title 10 War Games evolution (EW12).

(Marine Corps Warfighting Laboratory 2012) The team utilized modern USMC doctrine promulgated in Expeditionary Force 21 (EF21) to analyze this mission evolution and develop supplementary vignettes necessary to address the research questions. (United States Marine Corps 2014) The mission was decomposed and a phase selected for concept development. The team bounded and specified the operational concept of Phase III (Follow on Operations) into vignettes which supported options for MBSE development. A screening operation in a West Africa southern port city was selected for detailed development. The operation was further broken down into insertion methods, screening setup, and a battle engagement scenario. The team produced three operational scale levels for this vignette to address the operational force scale relationship to energy and effectiveness. The battle engagement scenario was ultimately selected for detailed modeling and simulation to support the AoA.

System function, form, and Measures of Effectiveness (MOEs) were allocated in the MBSE process, guided by USMC foundational documents, to aptly specify a range of military operations and range of scale suitable to the EW12 vignette that the team developed (Marine Corps Warfighting Laboratory 2012). Functional architecture was determined by examination of the Marine Corps doctrinally established tasking in context with the mission scenario developed (United States Marine Corps 2014). A functional hierarchy was then implied by tracing the low level functions back up to the appropriate warfighting function within the USMC doctrine. Physical architecture was constituted as a Special Purpose Marine Air Ground Task Force (SPMAGTF) in accordance with EF21 principles and the CONOP. (United States Marine Corps 2014) Three scales of force were specified for the SPMAGTF as 3-Platoon, 4-Platoon, and 5-Platoon. Table 1 and Table 2 depict the GCE and ACE composition for each platoon configuration:

Table 1. Barra Vignette 3 1st Company GCE Composition

3 Platoons

Unit	Marines / Unit	Locations	Total Marines
Fire Team (Reinforced)	5	6	30
Rifle Squad	8	3	24
81mm Mortar Squad	3	3	9
Observation Post	4	2	8
Convoy (3 HMMWVs)	5	3	15
Capt/Corpsman	3	1	3
		Total	89

QRF

Unit	Marines / Unit	Qty	Total Marines
Fire Team (Reinforced)	5	2	10
Rifle Squad	8	3	24
81mm Mortar Squad	3	0	0
		Total	34

4 Platoons

Unit	Marines / Unit	Locations	Total Marines
Fire Team (Reinforced)	5	8	40
Rifle Squad	8	4	32
81mm Mortar Squad	3	4	12
Observation Post	4	3	12
Convoy (3 HMMWVs)	5	3	15
Capt/Corpsman	3	1	3
		Total	114

QRF

Unit	Marines / Unit	Qty	Total Marines
Fire Team (Reinforced)	5	3	15
Rifle Squad	8	4	32
81mm Mortar Squad	3	1	3
		Total	50

5 Platoons

Unit	Marines / Unit	Locations	Total Marines
Fire Team (Reinforced)	5	8	40
Rifle Squad	8	4	32
81mm Mortar Squad	3	5	15
Observation Post	4	4	16
Convoy (4 HMMWVs)	5	4	20
Capt/Corpsman	3	1	3
		Total	126

QRF

Unit	Marines / Unit	Qty	Total Marines
Fire Team (Reinforced)	5	5	25
Rifle Squad	8	6	48
81mm Mortar Squad	3	2	6
		Total	79

Table 2. Barra Vignette 3 1st Company GCE Composition

3 platoons	QRF insertion	CAS	AirLOG	Total
CH-53K	1	0	0	1
MV-22	0	0	1	1
AH-1Z	0	1	0	1
4 platoons	QRF insertion	CAS	AirLOG	Total
CH-53K	1	0	0	1
MV-22	1	0	1	2
AH-1Z	0	1	0	1
5 platoons	QRF insertion	CAS	AirLOG	Total
CH-53K	2	0	0	2
MV-22	1	0	1	2
AH-1Z	0	1	0	1

A Function-to-Form allocation was made in order to insure adequate coverage for all required functionality. The MOEs were determined through examination and screening of metrics defined in the Marine Corps task list. (United States Marine Corps 2014)

Team Expeditionary designed and constructed three agent-based executable models using Map Aware Non-Uniform Automata (MANA) each of which were representative of a unique SPMAGTF force scale. The models adequately represented the maneuver and direct fires missions associated with the GCE of the SPMAGTF in the vignette of interest. Additional energy modeling of the ACE was performed using spreadsheet techniques to augment the GCE modeling and provide a basis for analyzing energy dependencies between the battle engagement and the ACE supporting elements of that engagement (United States Marine Corps 2014). MANA modeling included the modeling of an adversary which was consistent with the EW12 evolution and the CONOP. (Marine Corps Warfighting Laboratory 2012) The team planned and conducted MANA experiments, collected output which supported an effectiveness determination, and reduced the data pursuant to an AoA. Energy data was obtained through analysis of the SPMAGTF consumers in their operational context and according to energy dependencies established by the MANA experiments.

The AoA was supported by a framework discussion that assessed the methods, sources, and measures from which the AoA was performed. Additionally, the framework revisited the initial research questions and the mission success criteria in an effort to understand what steps would be necessary to complete the analysis. The MOEs were restated and traced to the methods employed for the study, functional hierarchy, requirements, and the effective need. Metrics from the MANA experiments were also traced to the operative experimentally supported MOE as well as to the dependencies in constructed metrics within the MANA output. The narratives that follow describe the analytical methods which were employed to merge the energy and effectiveness results to state ten specific tradespace results.

A mission energy link analysis was performed to augment the MANA experiments. The energy link analysis framed the study in terms of fixed and variable consumers in the battle space so that energy dependencies associated with the MANA battle engagement could be quantified. Certain MANA outputs, such as battle length, blue (friendly) agents killed, and blue agents injured were identified as key dependencies for the energy study. A base set of assumptions that corresponded to all three experiments were stated. The assumptions assisted in defining holistically the entire energy link associated with the full mission. This provided the necessary augmentation to the autonomous MANA modeling. The energy study developed full estimates analytically for the energy requirements corresponding to each of the three platoon sizes. An energy profile vs. time was created in each case showing consumption rates at each interval as well as cumulative energy consumption. Analysis by asset, mission, and fuel availability was performed to fully describe the energy space.

The tradespace analysis was conducted by examination of key relationships uncovered when the energy link analysis data was combined with experimental results from the MANA data. Five specific types of analyses were conducted to support the AoA. The LER analysis considered the blue force percentage losses as a ratio of the red force percentage losses. This method is useful for measuring outcomes in attrition warfare (Darilek et al. 2001). Losses were considered in terms of kills and injuries and plotted against total fuel for each force scale. The casualty loss exchange is depicted in Figure 1.

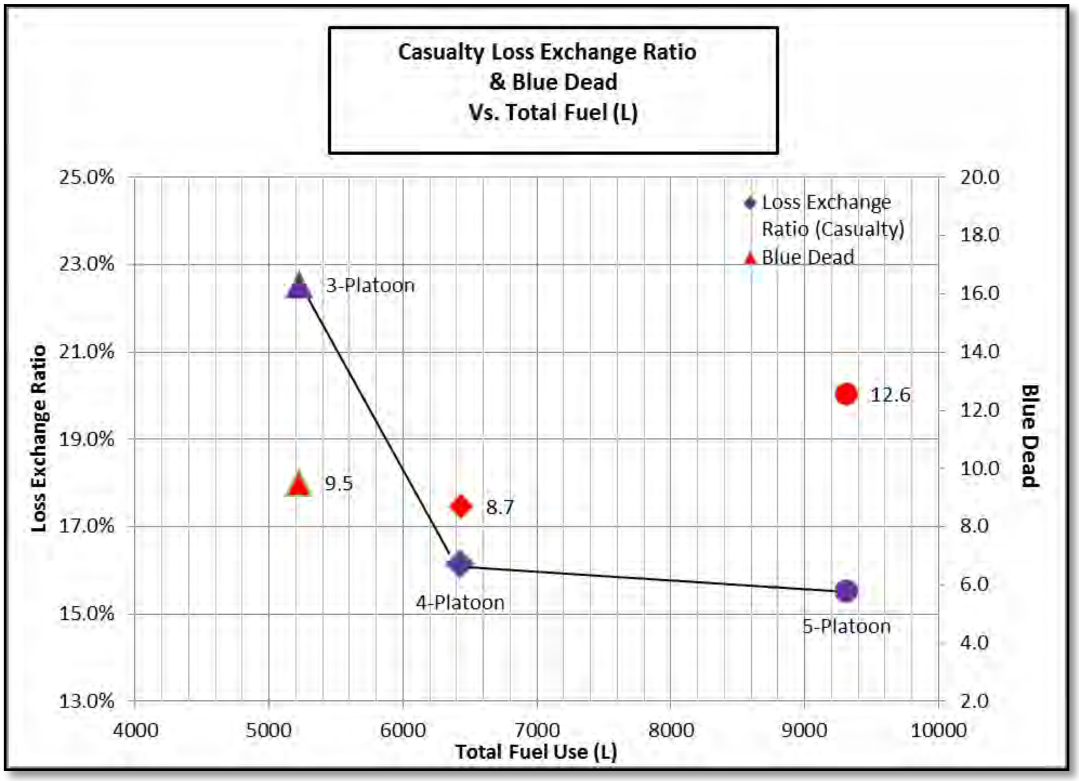


Figure 1. Loss Exchange and Blue Causalities

Fires efficiency analysis was conducted to examine how well forces directed fire and hit their targets. Blue force fires efficiency was plotted against red force fires efficiency for each blue force platoon configuration. Fires efficiency was of particular interest since it exposed the stochastic nature of the weapons profiling. Injury rates of the blue forces were examined as a function of the red fires efficiency to gain insight into the high blue force injury rates that existed for each platoon configuration. The injury rate measure was a key element in determining ACE asset requirements for conduct of the post mission medical evaluations. Sensitivity analysis was performed to examine the sensitivity of the blue injury rate to the red fires efficiency and red ammo expended. The sensitivity analysis was motivated by the high blue force injury rate and its relationship to the energy requirements. Battle length analysis examined the key attrition warfare phenomena at each platoon configuration and the relationship to ACE energy requirements for battle support. A successful mission determination was supported through the development of an efficient frontier trade study on the operational energy versus Overall Measure of Effectiveness (OMOE) for each platoon size. The following results of the tradespace analysis were used to support the four research findings articulated at the beginning of this summary.

1. Tradespace Analysis Result 1

Casualty LER results suggest that diminishing returns are present as energy costs are increased. The 4-Platoon level offers the lowest casualty count and second best LER for a marginal increase in total fuel use over the 3-Platoon level which has the lowest total fuel use.

2. Tradespace Analysis Result 2

When injuries are added into the LER calculation, it becomes clear that the LER values increase substantially due to the high blue injury rates. The high blue injury rates were believed to be a result of the close in battle mode used with limited Tactics Techniques and Procedures (TTP) and Situational Awareness (SA) implementation in the models.

3. Tradespace Analysis Result 3

Fires efficiency for the blue force is dramatically greater than that of the red force at each scale level because weapons targeting (probability of kill), armor protection, and armor penetration of the blue force were all superior to those of the red force.

4. Tradespace Analysis Result 4

The minimal degree of separation of the data points between the three platoon levels for fires efficiency suggests that the blue to red efficiency relationship is operative at all levels and that it is a fundamental aspect of the engagement

5. Tradespace Analysis Result 5

Injury rate analysis shows that very low red fires efficiency is still adequate to cause significant injuries to the blue force. This corroborated the fact that the red force had both adequate SA of the blue force and expended a considerable amount of ammunition.

6. Tradespace Analysis Result 6

Injury rate sensitivity analysis shows that blue injury rates are very sensitive to the red fires efficiency for all three platoon configurations, although the 5-Platoon case shows the least sensitivity. Additionally, red force ammo expended must be reduced to below 3000 rounds (by actions of the blue force) to reduce blue force injury rates below 10%. The sensitivity data suggested that attrition warfare was operative in the MANA experiment and that additional SA modeling techniques were appropriate to demonstrate realistic battle space understanding to include force protection while dominating the engagement.

7. Tradespace Analysis Result 7

The superior capability of the blue forces with respect to weapons and armor suggest that battle length is simply a matter of how many better equipped blue troops are in the battle. More troops generally equates to reduced battle length.

8. Tradespace Analysis Result 8

Diminishing returns similar to the LER result exists with regard to the battle length versus energy trade. The 4-Platoon level is dominant over the 5-platoon level. Additionally, the 4-Platoon level offers superior effectiveness over the 3-platoon level at a marginal increase in total fuel use.

9. Tradespace Analysis Result 9

OMOE versus energy shows that the 4-Platoon level offers the best overall alternative in the trade study. The 5-Platoon level is nearly dominated by the other two options. Review of the casualty data also suggested that more casualties occurred in the 5-Platoon case despite the fact the loss exchange ratio was slightly better. The 3-Platoon level represented the lowest effectiveness of the three options although in terms of effectiveness per total fuel use it had a similar result to the 4-Platoon configuration.

10. Tradespace Analysis Result 10

The successful mission determination showed that all missions are successful according to the criteria established, but the team did not accept the determination as adequate due to lack of experimental results for all dimensions of the war fighting spectrum.

REFERENCES

Darilek, Richard E., Walter L. Perry, Jerome Bracken, John IV Gordon, and Brian Nichiporuk. 2001. *Measures of Effectiveness for the Information-Age Army.* Santa Monica, CA: Rand.

International Council on Systems Engineering (INCOSE). 2007. "Systems Engineering Vision 2020." www.incose.org. Last modified September. http://www.incose.org/ProductsPubs/pdf/SEVision2020_20071003_v2_03.pdf.

Marine Corps Warfighting Laboratory. 2012. "Expeditionary Warrior 2012." Quantico, VA: United States Marine Corps.

United States Marine Corps. 2012. *U.S. Marine Corps S&T Strategic Plan - Leading Edge Technology for the Marines of Tomorrow*. Washington, DC: United States Marine Corps.

———. 2014. *Expeditionary Force 21.* Washington, DC: Headquarters United States Marine Corps.

———. 2014. "Marine Corps Task List (MCTL - 2.0)." Last modified January 2014. http://www.mccdc.marines.mil/Units/MarineCorpsTaskList.aspx.

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

Team Expeditionary would like to thank our advisors, stakeholders, local commands, and family members for their continued support and encouragement during this capstone project. Completion of this project would not have been possible without support, advice, and expertise provided along the way.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

In today's austere fiscal environment the United States Marine Corps (USMC) is motivated to return balance to the expeditionary strength, from base-to-battlefield. The Marines hope to increase their combat effectiveness by striking a balance between ethos, efficiency and renewable energy. The objective is to maintain combat effectiveness with reduced equipment and supply footprint (Marine Corps Expeditionary Energy Office 2011). This balance is depicted in Figure 1. Currently, in a rapid response to changing expeditionary threats, the USMC is lethal but inefficient. The rapid response necessary to adapt to the evolving threats has resulted in a tilt away from the historically fast and austere nature of the USMC. The requirement to return balance to the USMC expeditionary force structure is a fiscal issue but more importantly it is a security, safety, and operational effectiveness concern (Marine Corps Expeditionary Energy Office 2011).

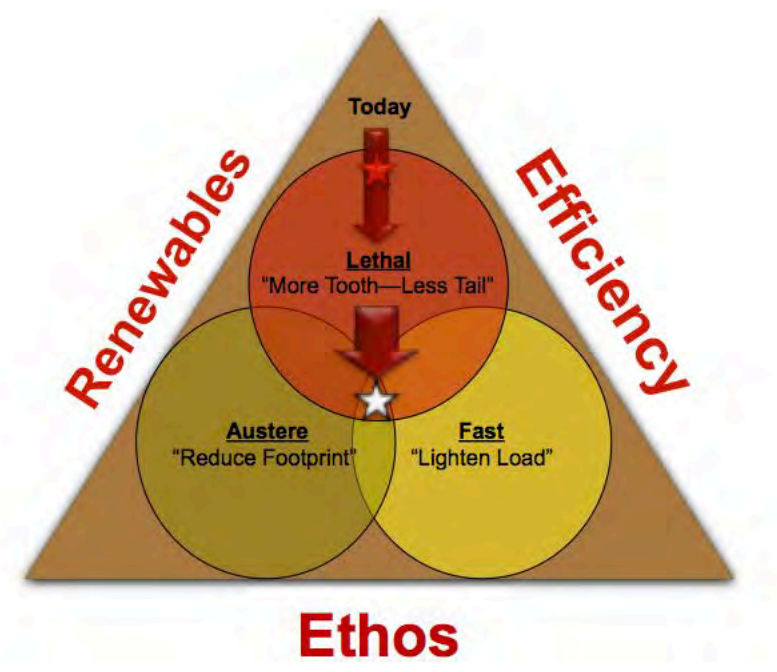


Figure 1. USMC Balance (from Marine Corps Expeditionary Energy Office 2011)

The current state of the expeditionary battle force has challenges that can be derived from the following major complications:

- Lives Risked/Lost: The USMC has identified that the energy supply chain puts Marines at risk and the effort to deliver energy to the Forward Operating Bases (FOBs) is a root cause (Marine Corps Expeditionary Energy Office 2011).
- Energy Costs: The USMC is fiscally constrained to today's Department of Defense (DOD) austerity and the increasing cost, demand, and instability of the energy markets has resulted in a high operation cost coupled with risk (Marine Corps Expeditionary Energy Office 2011).
- Highly Energy Dependent Technology: Material solutions for today's expeditionary needs are fuel and battery intensive, resulting in a growing demand for energy (Marine Corps Expeditionary Energy Office 2011).

To address the current challenges and fiscal climate the USMC has set goals, adhering to mandates, to reduce energy consumption across the spectrum of base-to-battlefield. At FOBs, the USMC aims to increase operational energy efficiency by 50 percent (Marine Corps Expeditionary Energy Office 2011). The goal is to reduce the fuel used per Marine by 50 percent (eight Gallons per Marine per Day (GPMD) to only four GPMD) by 2025 (Marine Corps Expeditionary Energy Office 2011). Additionally, in an effort to comply with all legislative and executive mandates, the USMC objectives are to reduce base energy utilization, measured by energy intensity, as shown in Figure 2.

E^2 GOALS	Efficiency Gains		
	2015	2020	2025
Embed E^2 Into USMC Ethos	25%	40%	50%
Lead and Manage E^2			
Increase Energy Efficiency of Weapons Systems, Platforms, Vehicles, and Equipment			
Meet Operational Demand With Renewable Energy			
Reduce Energy Intensity (EISA 2007)	From 2003 to 2015, reduce energy intensity at installations by 30%		
Reduce Water Consumption Intensity (EO 13514)	Through 2020, reduce water consumption intensity by 2% annually		
Increase Renewable Facility Energy (NDAA 2010, SECNAV)	By 2020, increase amount of alternative energy consumed at installations to 50%		
Decrease Petroleum Consumption (SECNAV)	By 2015 decrease non-tactical petroleum use by 50%		

Figure 2. Expeditionary Energy Office Goals (from Marine Corps Expeditionary Energy Office 2011)

The current state and future state are not entirely mutually exclusive in that efforts exist currently to explore and expand operational energy efficiency across the DOD. Figure 3 conveys the objective that the future state of the expeditionary forces will include a combination of the current state and the incorporation of the Expeditionary Energy Offices' (E2O) goals.

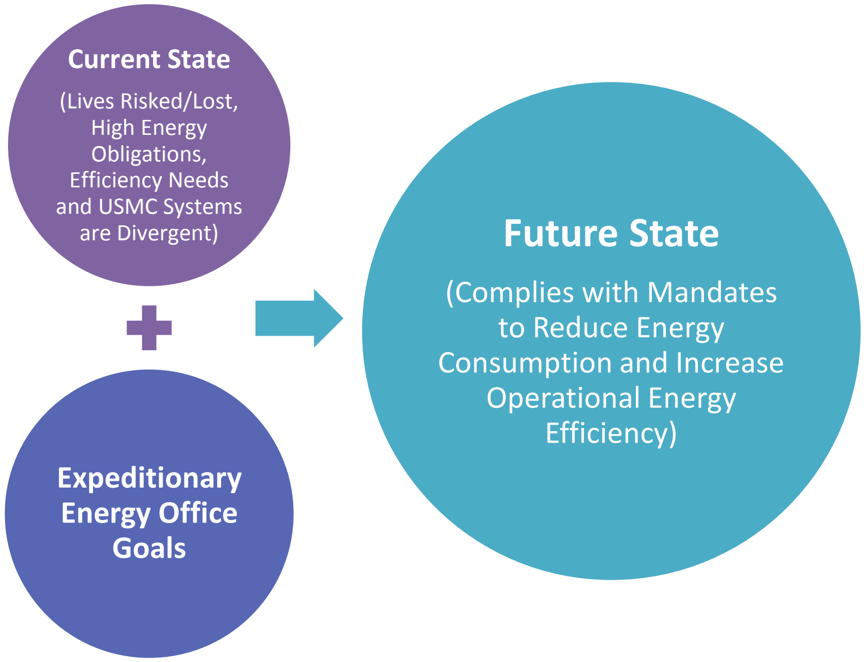


Figure 3. Future State of Expeditionary Operations

In order to reach the E2O's goals, changes in the current operations need to be made. These changes will come in the form of modernization of technology and integration of new strategies or procedures. In order to make these changes, investigations will need to be performed to determine where new materiel solutions or non-materiel solutions can be integrated into the current expeditionary operations without negatively impacting operational effectiveness.

Part of the investigations and insight into changes that could potentially help with the issues faced by the expeditionary forces will come from partnerships with academia. One such partnership includes this capstone project. Pursuant to closing the gap between the current and future state of expeditionary operations and in accordance with stakeholder guidance this capstone project addresses the following description of the problem:

> Use Model-Based Systems Engineering (MBSE) to examine both materiel and non-materiel factors regarding the conduct of an operationally successful, and energy efficient, Marine Corps expeditionary mission. (Naval Postgraduate School 2014)

> Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases. (International Council on Systems Engineering. (INCOSE) 2007)

Similarly, this project's approach embodies the practice of using visual tools and executable models throughout the systems engineering process to articulate and evaluate architectures which are relevant to a broad set of stakeholders. In particular, this capstone project used MBSE to create executable architectures that informed an understanding of the Operational Energy and Operational Effectiveness (OE^2) tradespace. The investigation built off of previous capstone efforts which examined Phases I and II of Expeditionary Warrior 2012 (EW12), and further extended the research into EW12 Phase III – follow-on operations (Vignette 3). The team focused on the contingency response functional architecture from USMC Concept of Operations (CONOPS) to facilitate the examination of operational scales of a Marine Expeditionary Brigade (MEB) force.

B. BENEFIT OF STUDY

As the fuel dependency of the United States (U.S.) Armed Forces continues to increase, the speed of deployment and movement is limited by supply restrictions. The increasing costs and danger of transporting fossil fuels to various mission essential locations have led to a demand for alternative energy and more efficient systems (Rosenthal 2010). The Marine Corps E2O has made energy one of its top priorities (Marine Corps Expeditionary Energy Office 2011)Building upon previous research, this study helps to provide additional analysis of the tradespace in order to find both materiel and non-materiel solutions to improve energy efficiency. Specifically, the study assesses the efficient energy application of the force structure to contingency operations while maintaining or improving operational effectiveness. Force scale, or the size and makeup of the unit are not clearly understood in terms of energy efficient application and the energy demands as it relates to the mission and human decision making. The research helps to inform the USMC regarding best practices for selection of force scale within the operational tradespace. The research also includes executable model artifacts which potentially can be integrated with working dashboard models in support of overarching E2O energy efficiency themes.

C. STAKEHOLDER IDENTIFICATION

Initial research into potential stakeholders resulted in the identification of the following:

- Marine Corps Expeditionary Energy Office
- End Users, Operators, Maintainers
- Marine Corps System Command (MARCORSYSCOM)
- Office of Naval Research
- Capability Development Directorate (CDD)
- Training and Education Command (TECCOM)
- Marine Corps Warfighting Laboratory (MCWL)

While not exhaustive, the preceding list does encompass those stakeholders that have the potential to benefit most from the results obtained during this effort. The Expeditionary Energy Office, represented by Colonel James Caley, sits at the top of the stakeholder list, and as such, has been the team's primary means of communication and insight into Marine activities, doctrine, and core values.

D. LITERATURE REVIEW

The team conducted a literature review in order to provide an informed basis for establishing the overarching research objective and questions for the capstone effort.

1. Research Methodology

As shown in Figure 4 this process utilized previous capstone projects and major USMC publications to form a foundation of research knowledge. This process or methodology provided the project with means to attain a set of relevant value-added research questions.

Figure 4. Initial Research Phase

Initial efforts included exploration of the Naval Postgraduate School (NPS) - E2O relationship. The next step in this methodology included a parallel exploration of both previous research conducted at NPS and a review of USMC and E2O publications. Lastly, the process was concluded with the formation of a set of research objectives and questions that are both relevant and able to expand the knowledge base.

2. Key Publications

The purpose of this initial phase of research was to build a research foundation upon which a properly aimed research project could emerge. The team surveyed various key publications to form an understanding of the background, solution spaces, previous topics of interest, and current gaps in the E2O's requirements. Figure 5 depicts the five major publications that were reviewed.

Figure 5. Major USMC Publications

a. *USMC Expeditionary Energy Strategy Implementation Planning Guide*

This guide expressed the needs and trends with respect to the USMC and energy. The team utilized this publication, available directly from E2O's website, to form an understanding of the history, purpose, and direction of the E2O and the DOD (Marine Corps Expeditionary Energy Office 2011).

b. *Expeditionary Force 21*

The Expeditionary Force (EF) 21 document introduced the team to the future expeditionary concept of the USMC. With this document, a foundational understanding of the structure and capabilities of the USMC was shaped. The document outlined the roles of the USMC, the purpose behind being an expeditionary force, and most importantly the structure concept of the USMC. The Marine Expeditionary Force (MEF), the Marine Expeditionary Brigades (MEBs), Marine Expeditionary Units (MEUs), and Special Purpose Marine Air-Ground Task Forces (SPMAGTFs) were all introduced and described in detail (United States Marine Corps 2014).

c. Expeditionary Warrior 2012 Final Report

To understand the context in which an expeditionary mission might be conducted, after attaining understanding of the USMC expeditionary structure, the team needed a source that describes mission scenarios. The team utilized EW12, one of the Marine Corps' Title 10 war-games, to understand a future scenario in which an expeditionary mission is carried out. The EW12 document introduced the team to the concept of the three major phases of an expeditionary mission: Achieve Access / Setting Conditions, Gain Entry, and Follow-on Operations. These three phases were supported by five scenario vignettes, which added detail to the scenario (Marine Corps Warfighting Laboratory 2012).

d. Draft MEB CONOPS (June 2014)

The MEB CONOPs enabled the team to identify assumptions about how the USMC implemented the various Marine Air-Ground Task Force (MAGTF) sizes. It also explained the concept of a scalable MEB. The MEB CONOP allowed the team to understand the limitations of the different size MAGTFs and provided insight into how MAGTFs are deployed and implemented. The document not only introduced the major research idea of scalability, but it also introduced the limited mission sets that a MEB can perform. These mission sets, defined by Marine Corp Tasks (MCTs) scoped a better understanding of MEB capabilities and requirements (United States Marine Corps 2014).

e. Marine Corps Task List (MCTL-2.0)

The MCTL allowed the team to better understand the MEB's relationship to the overall mission of the USMC. The document introduced sets of measures within each MCT that could guide the scenario design for modeling and simulation as well as the systems engineering process (United States Marine Corps 2014).

3. Previous Research

The team reviewed literature, including several capstone theses, which has emerged from the NPS and E2O relationship. Two major research project reports provided an orientation to applying system-engineering concepts and modeling and simulation to a problem space. The second half of the initial research phase of the research methodology aimed to understand the link between previous NPS MBSE capstones and the objectives this project undertook, as depicted in Figure 6.

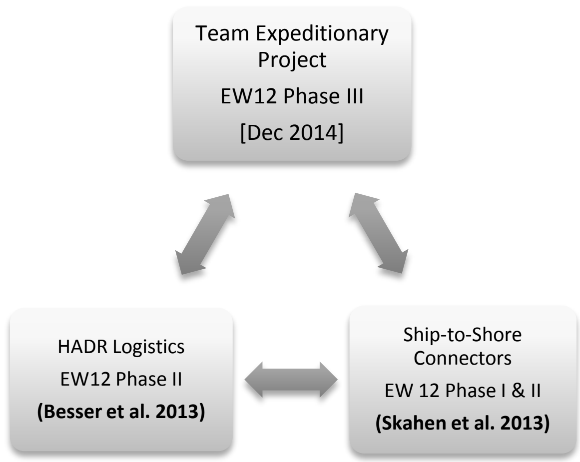


Figure 6. NPS Research Project Relationships

a. Expeditionary Energy Efficiency in Support of Foreign Humanitarian Aid/Disaster Relief

Even though stakeholders expressed interest, humanitarian mission research was not prevalent within E2O. The team determined this document both relevant and a crucial part of the energy efficiency knowledge base. Besser et al. research focused primarily on the logistics of providing aid in the form of fuel consumption and manpower to supply water and supplies to those in need. This research enabled an understanding of how a MBSE approach could be used to solve an energy problem and a method to establish mission context. Although Besser et al. (2013) focused on logistics, the research proved very valuable in terms of understanding equipment attributes and provided a summary of the Marine Air-Ground Task Force Power and Energy Model (MPEM). Despite having a different approach and solution set to the same E2O overarching mission, the document assisted in the formulation of our baseline understanding upon which research could be expanded. Besser et al. posed the following four questions during the analysis phase of their project.

1. What impacts to the FHA/DR mission are experienced due to non-material changes?

2. What impacts to the FHA/DR mission are experienced due to material changes?

3. Can any of the changes be combined to provide increased mission success?

4. What are the implantation actions needed to adopt promising changes?

b. Exploring the Reduction of Fuel Consumption for Ship-to-Shore Connectors of the Marine Expeditionary Brigade

Another interesting project produced by the NPS-E2O partnership, which focused primarily within the Gain Entry phase of EW12, led the team towards a possible Phase II or Phase III mission. Skahen et al. (2013) research provided a valuable source to the baseline knowledge of understanding the needs of the E2O. The project posed the following research questions:

1. Can Improved Fuel Efficiency be Reached through Changes in DOTMLPF while Maintaining Mission Capability?

2. What Particular Connectors Have the Most Effect on Fuel Efficiency?

3. Can the Environment Affect the Ability of the MEB to Achieve Better Fuel Efficiency?

Through the review of previous NPS works as well as the major USMC publications the overarching research objective and associated questions were developed for this capstone project.

E. RESEARCH OBJECTIVE

Through initial research efforts, and with input from the E2O, the team established the following overarching research objective: To establish an understanding of the relationship between MEB scale and certain objectives related to operational reach and operational energy within the context of a USMC expeditionary mission. The team further elaborated this objective with the following three research questions:

1. What is the energy cost associated with execution of a successful USMC expeditionary mission, where the measures of success are determined by Operational Effectiveness?

The first question was concerned with the energy cost associated with threshold success. The team pursued a definition of mission success and then performed experimentation to examine factors associated with the conduct of the successful mission.

2. What are the impacts of variations in MEB scaling on Operational Effectiveness and Operational Energy?

The second research question sought to provide an understanding of how variations in force scale in the Marine Expeditionary mission scenario affected the OE^2. Since the force structure can change as needed it is important to understand the costs associated with the variations in scaling of forces.

3. What is the USMC Operational Energy trajectory with regards to the tradespace between effectiveness, energy, and other measures as defined by USMC doctrine from the Expeditionary Energy Office?

The third and final research question formulated was developed to compare the current MEB OE^2 tradespace with the projected future MEB tradespace in order to identify the MEB capability trajectory in terms of the tradeoffs. This research question proposed a line of inquiry to support steering of the capability trajectory toward the center of the (fast, austere, and lethal) spectrum desired by the USMC.

F. SCOPE

Expeditionary Warrior 2012 Phase III was examined as the prime candidate for further mission analysis. Having already completed background research – including a review of EW12 Phase II and related NPS Capstone research, the team designed a vignette that included portions of the analysis completed for EW12 Phase II, and also expanded the solution space to include a follow-on operations aspect that examined air, ground, and sea elements of the operation. The created vignette, and associated CONOPS allowed the team to explore the tradespace associated with an operationally efficient and operationally effective Marine Corps expeditionary mission.

G. SYSTEMS ENGINEERING PROCESS

The Systems Engineering (SE) process that was utilized by the team during this project was a modified version of the V-Model depicted in Figure 7. The problem presented to the team was not a traditional SE problem; it was a research problem with an SE cycle embedded into it. This modified version of the traditional V-Model was selected because it provided the necessary structured approach to address this research problem and accounted for the iterative nature of the phases during the process. The traditional phases of the V-Model have been replaced by a set of phases that more appropriately align to completing a research project instead of creating a product like a typical Systems Engineering project. This V-Model clearly defines the steps that were needed to complete the research project starting at the initial primitive need and ending in customer satisfaction (Foorsberg and Cotterman 2005).

The process started with an initial primitive need and ended with findings and artifacts that provided value to the sponsor. The systems engineering process is broken down into the four main phases shown. On the left side of the systems engineering "V," three circular icons are shown for the first three phases. These icons show that these phases were iterative processes. Each of these phases involved progressively refining each portion of the phase as more information was gathered and feedback was provided.

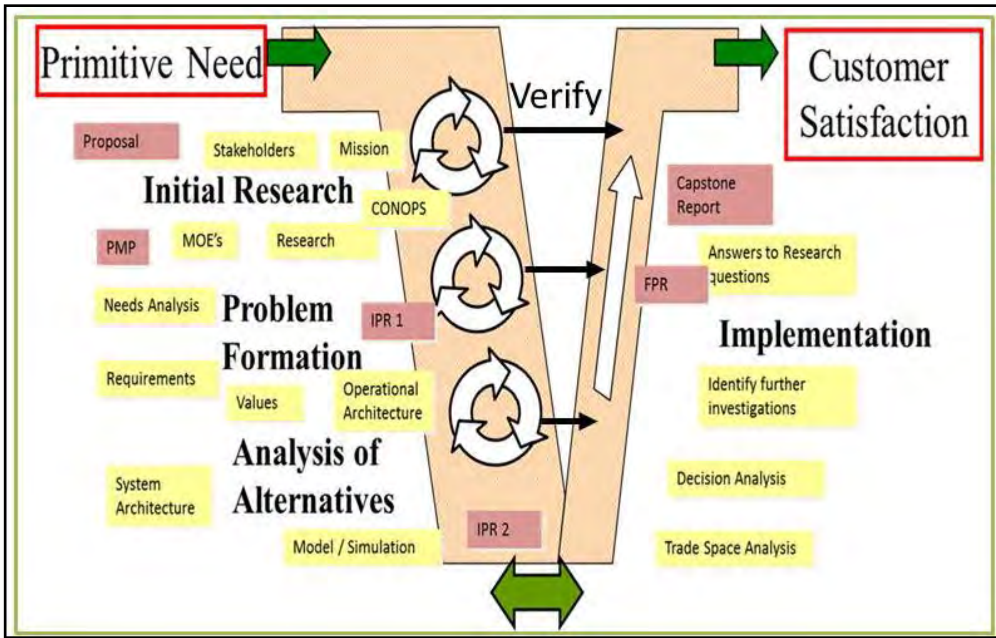


Figure 7. Systems Engineering Process, Modified V Model (after Foorsberg and Cotterman 2005)

The first phase, Initial Research, involved trying to understand the problem space, elicitation of information from the stakeholders to better understand the problem, and investigation of background information. The Initial Research phase helped to produce the research questions which the team determined to answer for this project. The yellow squares in Figure 7 show the smaller building blocks of the systems engineering process that were produced to help create not only the deliverables for the phases but also the overall project completion. In this initial phase the main deliverables, shown in red, include the proposal, the project management plan, and the first interim progress review.

In the second phase of the systems engineering process, Problem Formation, the team used the information that was learned in the first phase to formulate the problem definition and effective need statement. This process included defining the needs of the stakeholders to understand what is important to them, performing requirements analysis, and creating operational architecture views to fully define the problem space.

In the third phase of the systems engineering process, Analysis of Alternatives (AoA) was made possible through the specification and modeling of the system. The system functional, physical and allocated architectures were specified (Buede 2009). Alternative solutions were specified and modeled. Modeling included the examination and selection of methods and process to construct executable models from which data was produced to support the AoA.

A spiral development model was used to define the development of modeling in pursuit of full compliance to the engineering specification of the form, function, and the CONOP. The spiral approach laid a foundation capable of fulfilling capstone requirements while further spirals could expand the value if time permitted. Typically utilized in software systems engineering, the spiral methodology expands functionality of software with iterations. In this application, each spiral provided the process to enhance model resolution and value (Maier and Rechtin 2009). The main deliverable during this third phase was the second interim progress review.

The final phase of the systems engineering process used for this project included the Implementation of achievements in the first three phases. In this phase, the results from the modeling and simulation efforts were analyzed in order to answer the set of research questions formulated in the first two phases. Also identified during this phase were ideas for further investigation. The major deliverables for this final phase were the final progress report, the capstone report, and the modeling and simulation artifacts.

H. CHAPTER SUMMARY

The USMC wants to return balance among being fast, austere, and lethal to its expeditionary forces. To assist in this balancing E2O has set out a set of goals that focus on reducing the energy used and increasing overall efficiency of the forces. This capstone project helped to contribute to the overarching E2O goals of reducing the energy used by the expeditionary forces by investigating both materiel and non-materiel solutions. During an initial investigation of the problem space, a set of stakeholders were identified as well as a set of previous research and publications regarding expeditionary energy.

After reviewing the previous research and investigating the problem space, a research objective was formulated to assist in guiding the capstone project. A modified V-Model was also established as the systems engineering process to help provide a roadmap for completing the project. This information will be used in the next chapter to define the problem, determine requirements, and craft the operational architecture.

II. SYSTEMS ENGINEERING – PART I

A. INTRODUCTION

The initial research performed by the team provided the necessary background and context to successfully continue SE execution with the problem formation and AoA process steps. These two SE phases were fully articulated in Chapters II and III of this capstone report. Problem formation and AoA development serve to lay the foundation for informing modeling and simulation objectives. To achieve the desired outcome the team further detailed and defined the SE process as follows.

1. Step One: Refinement of Need

The team recognized that the existing need required additional refinement to address all of the stakeholders objectives and to further reduce the scope of the problem to one which the teams' efforts could add value. Additional stakeholder analysis was performed and a more narrow effective need was drafted which would allow the development of capstone relevant requirements.

2. Step Two: Requirements Analysis

The team determined that requirements analysis must originate from established doctrine such that subsequent allocation and decomposition would be representative of USMC architecture and practice. Consequently, the requirements analysis focused on association of the effective need with doctrinally established warfighting objectives defined in Marine Corps Doctrinal Publication (MCDP) 1–0. Additionally, the team recognized that full requirements analysis would be realized only with the final bounding of the mission context. Therefore, the initial requirements analysis was designed to establish both high level traceability to the effective need and the basis for allocation of requirements for the specific mission context ultimately employed for the modeling effort.

3. Step Three: Mission Analysis – Operational Concept

Mission Analysis and the development of the operational concept were performed to establish the context and details from the broader warfighting requirements. The analysis continued with the EW12 evolution and objectively sought to reduce scope while demonstrating traceability. The end goal of this effort was to establish the operational concept for the modeled segment specification that would allow specification of detailed functionality, measures of effectiveness, and physical properties of the system all which must be able to be decomposed from the high level USMC doctrine. Buede (2009) defines the operational concept as follows.

> Operational Concept: vision for what the system is (in general terms), a statement of mission requirements, and a description of how the system will be used.
>
> The operational concept includes a collection of scenarios (one or more for each group of stakeholders in each relevant phase of the system's life cycle).

4. Step Four: System Form and Function Specification

The team determined it was necessary to specify the system form and function to provide the level of detail necessary for supporting the modeling of the system. The effort utilized the MCT doctrine to tailor functional elements and measures within the broad war fighting taxonomy of the USMC. Physical architecture was pursued to establish a product baseline from MAGTF elements necessary to operationally support the functional requirements. In contrast to Step 3, this section maintained a very narrow scope to focus on the tradespace and modeling support aspects of the project. This process step also includes definition of attributes of the enemy force to support the modeling.

5. Step Five: System Representation in Executable Model

Modeling and simulation are fully described in Chapter IV. The system was represented operationally through the construction of executable models. The modeling process established the paradigm, tools, input considerations, model design, output considerations, and experimentation necessary to obtain data for the AoA.

6. Step Six: Analysis of Alternatives

The AoA is fully elaborated in Chapter V and was composed of the following elements. A framework, which examined the research questions, MOEs and experimental metrics, established the method for performing the trade study. The mission success determination was conducted for each alternative. Effectiveness and energy analysis was conducted. Finally, the tradespace was analyzed and results tabulated.

B. NEEDS ANALYSIS

1. Primitive Need

During the initial research phase the team developed an overarching objective from the primitive need statement provided by NPS. The overarching objective was used to determine appropriate research questions thereby setting the goals for the project. The team provided additional analysis of this initial finding as described herein. The initial understanding of need was submitted to stakeholder analysis to formulate an effective need as show in Figure 8.

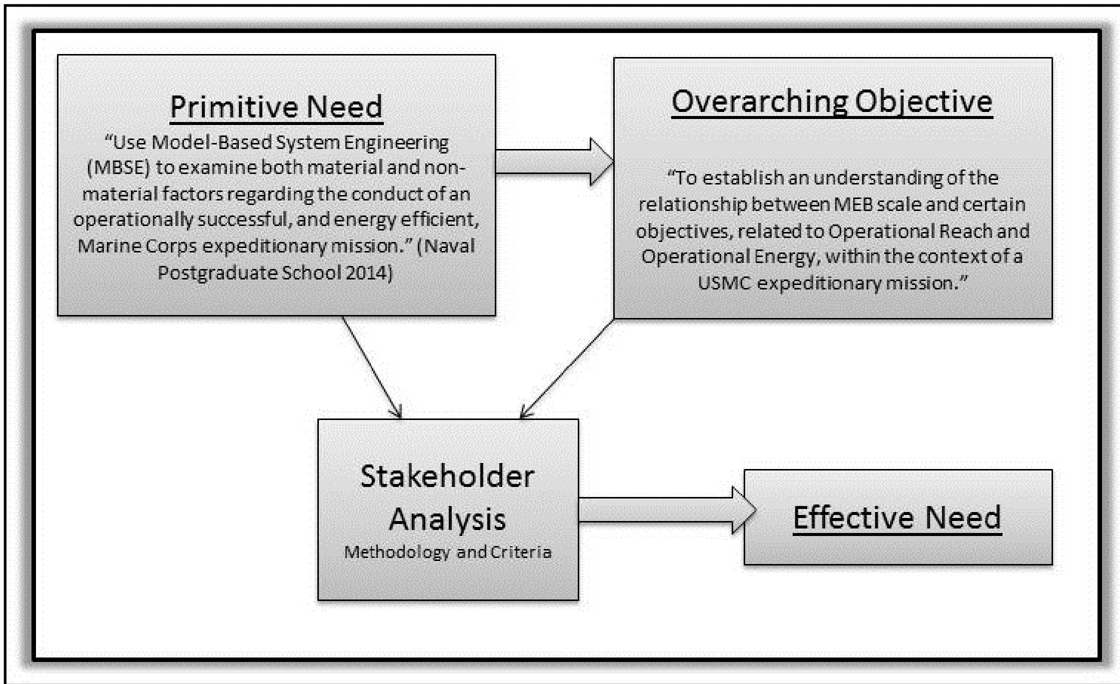


Figure 8. Primitive Needs Analysis (after Driscoll and Kucik 2011)

2. Stakeholder Analysis

The primitive need and overarching objective were subjected to a stakeholder analysis of the key stakeholders identified in the initial research phase through additional research, direct contact, and construction analysis. Table 1 summarizes the findings of the stakeholder analysis. The analysis methodology and findings consisted of the following (Nelson 2013).

a. Assign Precedence

Primary and secondary stakeholders were determined based upon the following criteria. Primary stakeholders are those who are mandated to provide leadership and coordination of expeditionary energy investigations or are direct users of materiel and non-material solutions in the expeditionary environment. Secondary stakeholders may be benefactors of energy studies or may participate in research, but are precluded by the primary criteria.

b. Elaborate Identification

Details about the origin and purpose of the stakeholders are provided to facilitate an understanding of the stakeholder's perspective.

c. Establish Individual Primitive Need

A primitive need for the stakeholder was constructed based on the initial understanding about the stakeholder's perspective. That is, the primitive need was based on the organizational purpose, intent, and direction without bound or restriction to some objective such as those which were determined for this capstone project.

d. Establish Individual Effective Need

Each stakeholder's primitive need was analyzed and bounded in terms of the objective of this capstone to construct a relevant effective need which still maintained the particular stakeholder's perspective.

e. Identify Individual Objective

The objective statement for each stakeholder was constructed to provide a full set of end states from which capstone alternative objectives could be explored.

f. Individual Stakeholder Analysis

E2O provides leadership for the investigation of energy efficient solutions that support an operationally capable force which must defeat 21st Century threats in a scarce energy environment. E2O meets the criteria for primary stakeholder. As such the E2O objectives have significant bearing on the formulation of the aggregate effective need. The team concluded from the E2O perspective that an important step in being able to support E2O's effective need is to understand the energy consumption of the current force structure in a relevant operational context. Additionally, the team determined it would be beneficial to develop a robust operational context and provide foundational support for future research through identification of methods and practices for modeling.

End users, operators, and maintainers were also considered primary stakeholders. In order to maintain a balanced perspective the team determined it was necessary to include users of the organic capability as primary. The effective need of the end users, operators, and maintainers is to complete mission objectives in a fast, austere, and lethal manner (United States Marine Corps 2014). The fast, austere, and lethal characteristics are considered to be out of balance. The aggregate effective need was influenced significantly by this fact.

The MARCORSYSCOM was included in the group of secondary stakeholders based on the acquisition role. MARCORSYSCOM's effective need is to provide energy efficient, effective, supportable, and affordable materiel solutions for the warfighter. This stakeholder's perspective was seen as being significant to the extent the research findings would impact life cycle acquisition, as in development of materiel solutions. Although guidance indicated materiel solutions should be considered, the team determined that the scope of materiel solutions would be limited to selection from within existing architectures.

The Office of Naval Research (ONR) was considered a secondary stakeholder. Their effective need is to explore science and technology (S&T) objectives that relate to expeditionary energy as discussed in the Marine Corps S&T Strategic Plan (United States Marine Corps 2012). ONR is particularly interested research efforts that will support bringing expeditionary solutions rapidly to the technical community. The team determined that while ONR would not directly influence the aggregate effective need statement for this project, they may benefit from findings of the trade study.

The TECCOM was considered to be a secondary stakeholder. This command would be responsible for incorporating any gained knowledge that would lead to modifications in Marine Corps training. Their effective need is to ensure that new energy efficiency knowledge is quickly and reliably transferred to the Marines. This stakeholder's perspective influenced the research to the extent the team seeks to find trainable solutions.

Additional secondary stakeholders included the MCWL and the CDD. The MCWL's effective need is to identify and understand new tactics, techniques, and procedures (TTP) through expeditionary scenario development (Marine Corps Warfighting Laboratory 2012). The MCWL's effective need was considered to be highly correlated to this capstone projects EW12 scenario use and subsequent model development. The CDD's effective need is to develop and integrate energy efficient and effective Marine Corp warfighting capability (Marine Corps Expeditionary Energy Office 2014). CDD is concerned with identification and closure of capability gaps. Additional traceability to CDD gaps was not determined beyond that of the broad energy efficiency issue, although an expectation of the team was that findings would support closure of additional CDD gaps.

g. Summarize Conclusions

The team concluded the stakeholder analysis with a finding that balanced the precedence and preference of the stakeholders with the ability of the capstone team to extend the research in the energy space. The finding was used to update the initial need statement and overarching objective for the capstone project. The initial research questions were not modified in this process.

Table 1. Effective Needs of the Primary and Secondary Stakeholders

Stakeholder	Category	Description	Primitive Need	Effective Need	Goal
Marine Corps Expeditionary Energy Office (E2O)	Primary	E2O Representatives, Tasked to utilize Academia for Operational Energy Solutions (Marine Corps Expeditionary Energy Office 2011)	Reduce Energy Consumption of Marine Expeditionary Force	Provide an Operationally Capable Force for 21 Century Threats in Scarce Energy Environments	Expand Body of Knowledge Related to Operational Energy Obtain Insightful Information from Model Findings
End Users, Operators, Maintainers	Primary	MEU/MEB End Users, Maintainers, Command Infrastructure	Conduct Successful Mission	Complete Mission Objectives in an Fast, Austere and Lethal Manner (United States Marine Corps 2014)	Preserve and Uphold Operational Effectiveness
Acquisition Community (MARCORSYSCOM)	Secondary	"MCSC is the Commandant of the Marine Corps' agent for acquisition and sustainment of systems and equipment used to accomplish their warfighting mission" (Marine Corps System Command 2014).	Reduction in cost and footprint of material solutions for expeditionary warfighters.	Energy efficient, effective, supportable and affordable materiel solutions for warfighter	Acquisition cost reductions without impact to effectiveness or supportability
Office of Naval Research (ONR)	Secondary	"ONR coordinates, executes, and promotes the science and technology (S&T) programs of the United States Navy and Marine Corps. ONR's directorates balance a robust S&T portfolio, allocating funds to meet the warfighter's requirements" (Marine Corps Expeditionary Energy Office 2014).	Expansion of body of knowledge regarding energy use in Naval / Marine operational environments IAW defined S&T Objectives	Explore S&T Objectives that relate to Expeditionary Energy as called out in 2012 Marine Corps S&T Strategic Plan	Bring Expeditionary solutions rapidly to the technical community.

Stakeholder	Category	Description	Primitive Need	Effective Need	Goal
Capability Development Directorate (CDD)	Secondary	"Operating under the Deputy Commandant for Combat Development & Integration, the Director of CDD develops and integrates warfighting solutions enabling an effective Marine Corps capability to respond to strategic challenges and opportunities" (Marine Corps Expeditionary Energy Office 2014).	Identification of operational energy capability gaps in relation to expeditionary Marine Corp operations	Develop and integrate energy efficient and effective Marine Corp warfighting capability	Closure of capability gaps associated with Marine Corps operational energy and effectiveness
Training and Education Command (TECCOM)	Secondary	"TECOM develops, coordinates, resources, executes, and evaluates training and education concepts, policies, plans, and programs to ensure Marines are prepared to meet the challenges of present and future operational environments" (Training and Education Command United States Marine Corps 2014).	Maintenance of current and accurate training portfolio for the warfighter	Insure that new knowledge is efficiently and quickly transferred to Marines	Trained, and responsive Marine Corps
Marine Corps Warfighting Lab (MCWL)	Secondary	"Through innovation and experimentation, MCWL produces solutions for the Corps' operating forces. MCWL creates technological and strategic advances in response to the needs of today's warfighter. Commanding General, MCWL chairs the ExFOB Executive Integrated Process Team" (Marine Corps Expeditionary Energy Office 2014).	Relevant war games to understand global threats and appropriate Marine Corps response	Identification of new understanding in Tactics, Techniques and Procedures (TTP) through Expeditionary operational scenario development	Creation and facilitation of annual Title 10 War Games

3. Effective Need

The initial problem statement and overarching objective were revised to incorporate the stakeholder summary conclusions with the final effective need statement determined. The effective need combined with the original research questions established in Chapter I provide the guiding principles for requirements and architecture development that follow.

a. Statement of Effective Need

Team Expeditionary will use Model-Based Systems Engineering (MBSE) to examine both materiel and non-materiel factors regarding the conduct of an operationally effective, and energy efficient, Marine Corps expeditionary mission. Material factors will be constrained to solutions from existing and planned USMC architectures. The research will link the relationship between operational energy and operational effectiveness in a balanced manner to support realignment of the fast, austere, and lethality objectives of the USMC.

The MBSE may use existing Title 10 War Games evolutions to the extent practical and which allows the continued development of extensible research. In the conduct of MBSE, the team will gain an understanding of the operational energy consumption of the current and future force structure in an operational context that is representative of existing and anticipated environments.

The team will develop a robust operational context to support both the modeled and un-modeled scenarios. Support for the modeled scenario will be adequate to enable obtaining data sufficient to facilitate an understanding of the tradespace. Whether modeled or un-modeled the robust operational context will provide foundational support for future research, benefit existing research efforts in the energy community and provide input for capability gap re-assessment.

C. REQUIREMENTS ANALYSIS

As discussed previously, requirements analysis for this system originated from established doctrine such that subsequent allocation and decomposition was representative of USMC architecture and practice. Requirements analysis using the effective need resulted in an understanding of requirements both for the notional system and the operation context for modeled and un-modeled scenario development.

1. Requirements for system performance baseline development

A system capable of performing an operationally successful, energy efficient Marine Corps expeditionary mission was considered. The duality of this basic effective need along with the need to demonstrate scale determined the attributes of the system. The attributes were further decomposed in the sections that follow.

1. Attribute 1: The system must be operationally effective.
2. Attribute 2: The system must be energy efficient.
3. Attribute 3: The system must be scalable from doctrinally established USMC architectures both functionally and physically.

a. Attribute 1: Operational Effectiveness Requirements (OER)

For the purpose of this requirements analysis, a USMC system, which is operationally effective, must be capable of performing a range of military operations which are doctrinally supported, have full functionality established, have well developed measures, and are supported by existing TTPs. MCDP 1-0 establishes the six warfighting methods and MCTL 2–0 decomposes functionality with measures pursuant to their objectives. The requirements listed in this section represent the high level functional requirements from which allocated functionality and metrics to execute and assess a scoped mission was later developed.

1. The system must support **MANEUVER**

MCDP 1-0 defines Maneuver as indicated below.

Maneuver is the employment of forces in the operational area through movement in combination with fires to achieve a position of advantage in respect to the enemy in order to accomplish the mission. (JP 1–02) Maneuver allows for the distribution or concentration of capabilities in support of a commander's concept of operations. The Marine Corps maneuver warfare philosophy expands the concept of maneuver to include taking action in *any* dimension, whether temporal, psychological, or technological, to gain an advantage. (United States Marine Corps 2011, A-3)

2. The system must support **INTELLIGENCE**

MCDP 1-0 defines Intelligence as indicated below.

Intelligence provides the commander with an understanding of the enemy and the battle space and identifies the enemy's centers of gravity and critical vulnerabilities. It assists the commander in understanding the situation, alerts him to new opportunities, and helps him assess the effects of actions upon the enemy. Intelligence drives operations, is focused on the enemy, and supports the formulation and subsequent modification of the commander's estimate of the situation by providing as accurate an image of the battle space and the enemy as possible. It is a dynamic process used to assess the current situation and confirm or deny the adoption of specific COAs by the enemy. It helps refine the commander's understanding of the battle space and reduces uncertainty and risk. (United States Marine Corps 2011, B-3)

3. The system must support **FIRES**

MCDP 1-0 defines Fires as indicated below.

Fires use weapon systems to create a specific lethal or nonlethal effect on a target. Fires harass, suppress, neutralize, or destroy in order to accomplish the targeting objective—whether to disrupt, delay, limit, persuade, or influence. Fires include the collective and coordinated use of target acquisition systems, direct and indirect fire weapons, armed aircraft of all types, and other lethal and nonlethal means. Fires are normally used with maneuver and help shape the battle space, setting conditions for decisive action. (United States Marine Corps 2011, B-3)

4. The system must support **LOGISTICS**

MCDP 1-0 defines Logistics as indicated below.

> Logistics encompasses all activities required to move and sustain military forces. At the tactical level, logistics is combat service support and involves arming, fueling, maintenance, transportation, supply, general engineering, and health services. (United States Marine Corps 2011, B-3)

5. The system must support **COMMAND AND CONTROL**

MCDP 1-0 defines Command and Control as indicated below.

> Command and control is the exercise of authority and direction by a properly designated commander over assigned and attached forces to accomplish a mission. Command and control involves arranging personnel, equipment, and facilities to allow a commander to extend his influence over the force during the planning and conduct of military operations. Command and control is the overarching warfighting function that enables all of the other warfighting functions. (United States Marine Corps 2011, B-1)

6. The system must support **FORCE PROTECTION**

MCDP 1-0 defines Force Protection as indicated below.

> Force protection is the measures taken to preserve the force's potential so that it can be applied at the appropriate time and place. It includes those measures the force takes to remain viable by protecting itself from the effects of adversary activities and natural occurrences. Force protection safeguards friendly centers of gravity and protects, conceals, reduces, or eliminates friendly critical vulnerabilities. (United States Marine Corps 2011, B-3)

b. Attribute 2: Energy Efficiency

The system must provide a high return of mission effectiveness for total mission energy expended. This capstone project examined alternative solutions each having different energy efficiencies. The energy efficient operationally effective system determination was ultimately inferred from the tradespace analysis.

c. Attribute 3: Scalability

1. Function Scalability

The system function must be able to be described by MCTL 2–0 in adequate detail to provide traceability to each of the six warfighting functions. System function in a bounded scenario must represent operational scale on the basis of this traceability.

2. Form Scalability

The system form must be able to be described from USMC physical architecture definitions in MCDP 1-0 at an elemental MAGTF level. System form in a bounded scenario must represent operational scale on the basis of this elemental description.

d. Measures of Effectiveness

Metrics for high level warfighting functions were not determined to be applicable at this level of scope. The team determined that MOEs must be tailored from the MCTL 2–0 at the lowest level of functionality that the operationally bounded system must perform, and then constructed to represent the high level measures. Eventually, meta-modeling was used to adapt executable model outputs to a MOE compositing scheme which facilitated the description of the tradespace. The tailoring process was performed in conjunction with the functional decomposition in Chapter III. The methods for framing the tradespace including how the MOE compositing was performed are described in Chapter V.B.

2. Requirements for operational scenario development

a. Model Based Systems Engineering

The system must be able to be represented in an executable operational model to support data farming in pursuit of answering the research questions. According to Kusiak data farming is defined as follows.

> Data farming is concerned with methods and processes used to define the most appropriate features for data collection, data transformation, data quality assessment, and data analysis. (Kusiak 2005)

Model resolution must support the operational context for gathering tradespace data; however, high resolution is not mandatory so long as operational entities and their functionality can be adequately modeled to determine the trades and resolution assumptions and their impacts are well understood.

b. Title 10 War Games

In support of the MCWL, it is desirable to use existing Title 10 War Games evolutions to demonstrate extensibility of existing research (Marine Corps Expeditionary Energy Office 2014). This supports follow on research and produces artifacts which have relevance to existing work. The team elected to fulfill this requirement through the use of the EW12 scenario development.

c. Robust Operational Context

The scenario selected and developed should provide a robust operational context for the modeled and un-modeled portions of the scenario to support the objectives enumerated below.

1. Enable farming of data which is necessary to establish a tradespace between operational energy and operational effectiveness.
2. Provide a foundation for future research.
3. Provide a benefit for existing research.
4. Provide input for capability gap re-assessment.

D. MISSION ANALYSIS – OPERATIONAL CONCEPT

1. Background

The team pursued analysis of an operational scenario that supports adequate coverage of an end to end Marine Corps mission. The mission analysis and subsequent operational concept development supported a MBSE approach to identification of the Operational Energy and Operational Effectiveness tradespace pursuant to the research questions. Accordingly, the mission analysis defined the various levels of involvement of

Marine and other joint and combined forces as related to specific mission scenarios developed from the culmination of details provided in the documents listed below.

- MEB CONOPS
- EW12
- EF21

a. Marine Combat Support Elements and Expeditionary Force 21

EF21 provided base concepts for the teams' development of the mission. In particular, "Expeditionary Force 21 provides an aspirational vision of how we will operate in order to guide experimentation, force development activities, and inform programming decisions" (United States Marine Corps 2014, 4). Additionally, EF21 strives to paint the picture of "the right force in the right place at the right time." (United States Marine Corps 2014, 4) In keeping with these principles, and the idea of a more operationally capable, forward deployed force, the mission and concept development in this section employs the key foundations required to deliver a fast, lethal, and austere force to the fight. In order to accomplish this goal, the team employed a build-up of a MAGTF: Command Element (CE), Ground Combat Element (GCE), Aviation Combat Element (ACE), and Logistics Combat Element (LCE). Together these elements, in conjunction with naval support off-shore, provided the necessary force to accomplish the objectives of the mission.

In an effort to maintain consistency with Marine Corps force structure as outlined in EF21, the following Marine elements – which are the building blocks of the MAGTF – were used to compose the fighting force responsible for the mission (United States Marine Corps 2014).

1. Command Element

A Local CE is represented as the Commanding Officer (CO) in the local area of interest. The Local CE reports back to mission headquarters for the area of operations (United States Marine Corps 2014).

2. Ground Combat Element

The GCE is the main fighting force for ground operations. The GCE conducts a variety of missions from land operations to amphibious operations including reconnaissance and security operations (United States Marine Corps 2014).

3. Aviation Combat Element

The ACE provides an additional element of support for the ground troops. The ACE responsibilities include flying routes in advance of ground troops to clear the way, providing on-site presence during troop insertion, and providing fires support operations when necessary. Aviation elements fulfill a logistical role including flying resupply operations for food, water, munitions, and medical supplies. Aviation elements also conduct casualty evacuation (United States Marine Corps 2014).

4. Logistics Combat Element

The LCE provides the Marines on the ground with a method of sustainment. The LCE has the ability to encompass air, land and sea elements. Mission development in this section elaborates multiple methods of logistic support (United States Marine Corps 2014).

5. Sea Support Element

The Sea Combat Element (SCE) provides both a platform for logistics support and for mission support. In order to maintain supply lines, supplies can be periodically pulled from Sea Based Assets (SBAs) and passed to forward operating forces. The SBAs assets can also be utilized for strategic missile strikes in support of ground operations (United States Marine Corps 2014).

b. Expeditionary Warrior 2012 Evolution

The team selected EW12 as the basis for development of the robust operational context. The narratives in Chapters II.D.1 through Chapter II.D.3 are intended to provide the full context of the mission including decomposition as appropriate. Chapter II.D.4 provides the detailed operational development for the mission vignette that contains the segment which was specified for modeling. EW12 describes the situation in the politically unstable West African nation Savanna. Savanna comes under attack from neighboring nations and internal irregular enemies seeking to overthrow the Savanna Government. In the scenario, the Free Savanna Movement (FSM) consists of pockets of resistance throughout the Savanna nation. The West African Federation (WAF) is the invading enemy nation that lies directly to the South of Savanna and which provides the main organized fighting force that is used to overthrow the government and capture key cities in Savanna (Marine Corps Warfighting Laboratory 2012).

2. Enemy Offensive

A WAF/FSM offensive occurs in which enemy forces—in coordination with pockets of FSM resistance—proceed north across the Savanna Southern Border (as depicted in Figure 9) and attack/capture key cities in Savanna including: Banjul, Touba, Kaolack, and Dakar. In addition to the aforementioned cities, the WAF/FSM offensive also attacks the Savanna Islands—a small island chain located roughly 600 km off the west coast of Savanna, which provide potential Ariel Points of Debarkation (APODS) and Sea Points of Debarkation (SPODS) for a potential counter-offensive. A summary of the enemy forces reveals both "conventional and unconventional adversaries armed with credible Anti-Access/Area-Denial (A2/AD) capabilities including Surface-to-Surface Ballistic Missiles (SSBMs), Anti-Ship Cruise Missiles (ASCMs), Integrated Air Defense Systems (IADS), small boats and submarines" (Marine Corps Warfighting Laboratory 2012, 7). The initial offensive concludes with key cities now under WAF/FSM control and anti-access measures in place to thwart potential attacks initiated by the United Nations Security Council (Marine Corps Warfighting Laboratory 2012).

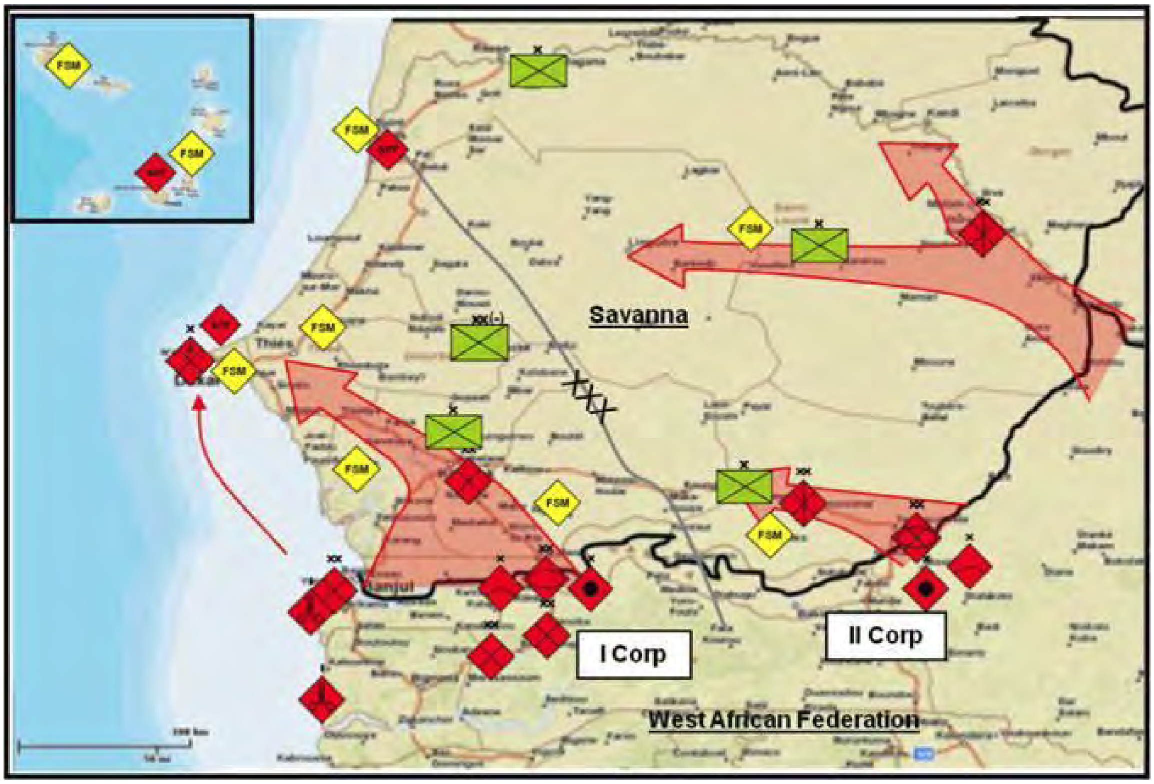


Figure 9. WAF/FSM Initial Offensive (from Marine Corps Warfighting Laboratory 2012)

3. Operation Restore Sovereignty

In response to the attacks initiated by WAF and FSM, the United Nations Security Council authorizes the use of a U.S. led coalition Combined Joint Task Force (CJTF) Savanna to re-establish the territorial integrity of Savanna and neutralize WAF's offensive capability (Marine Corps Warfighting Laboratory 2012). Charged with the following mission statement, CJTF Savanna established and executed a five phase approach to the campaign (Marine Corps Warfighting Laboratory 2012).

a. Mission Statement

> When directed, CJTF Savanna will conduct Operation Restore Sovereignty to re-establish the territorial integrity of Savanna, neutralize WAF's offensive capability and transition security responsibilities to U.N. forces. (Marine Corps Warfighting Laboratory 2012)

b. Mission Phases Defined

Phases I – III provide the basis for coalition forces to neutralize enemy A2/AD threats, gain entry to Savanna through certain key cities, and establish positions to support follow-on operations. The final two Phases IV and V entail stability operations and the transition to U.N. operations. In order to remain consistent with the themes from EW12, Phases IV and V were not developed, as they did not fall within the scope of the objectives for this research (Marine Corps Warfighting Laboratory 2012).

The Operation Restore Sovereignty mission decomposition shown in Figure 10 depicts the three levels of hierarchy that are consistent with the mission scenario established in EW12. The three phases of the operation are intended to execute in series such that objectives of each phase are considered necessary to set entry conditions for the following phase. The narrative of Chapter II.D.3.c develops the context of each phase to support the evolution up to the vignette definition in Chapter II.D.3.d. Vignette development in Phase III marks the point in the mission evolution where the team exercised academic liberty to create operational situations conducive to the energy study. The team ultimately selected Phase III (Support Follow-on Operations: Vignette 3) for detailed modeling, although each vignette description is rich with explanations of intention and suggestions for future analysis. Figure 11 shows the West Africa map with the key cities, mission phases, and the Follow-on Operations vignettes of interest.

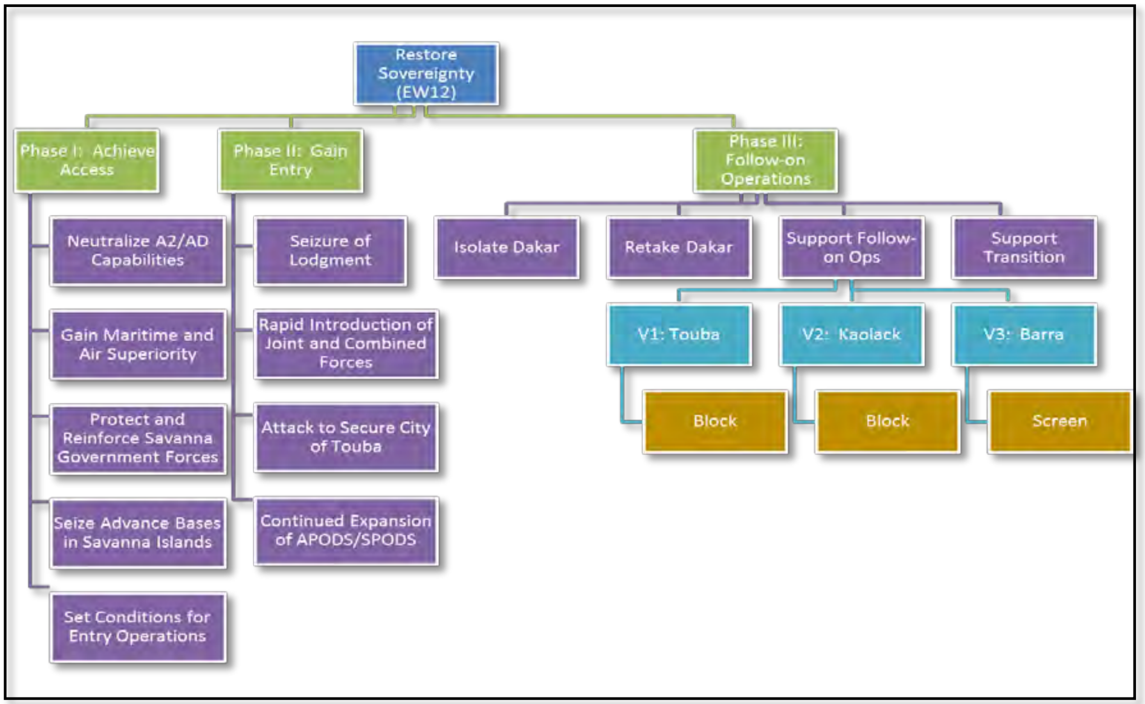


Figure 10. Operation Restore Sovereignty Mission Hierarchy

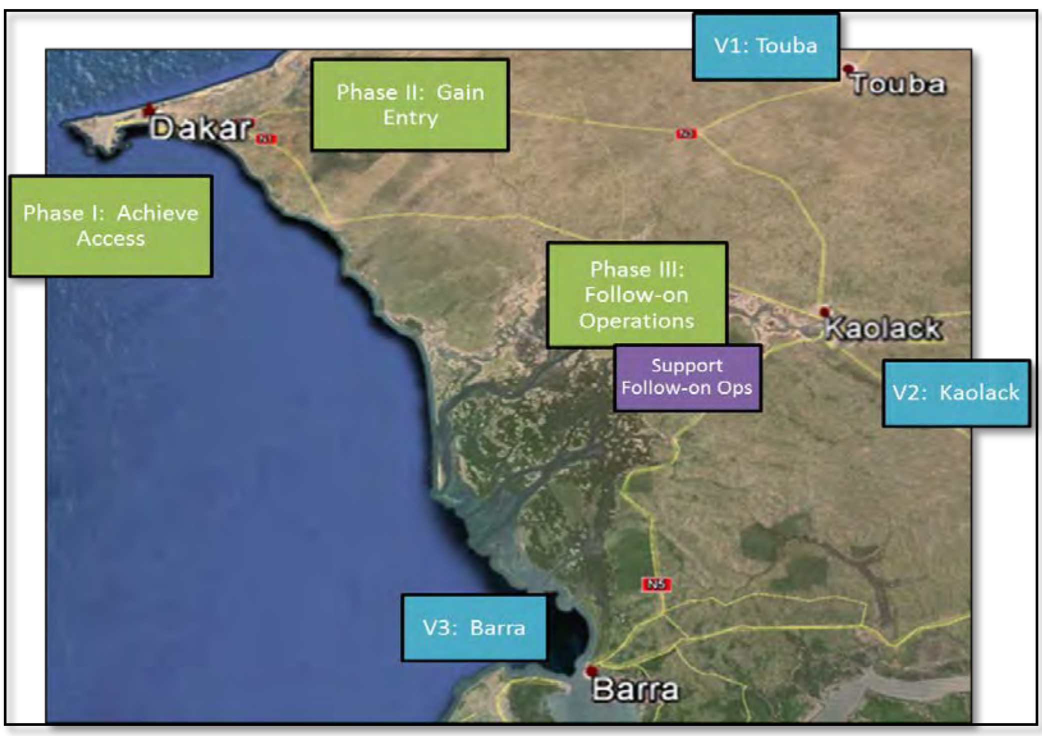


Figure 11. Operation Restore Sovereignty Area of Operations Map

c. Mission Phases Elaborated

1. Phase I: Achieve Access / Setting Conditions

During Phase I of Operation Restore Sovereignty CJTF Savanna forces perform initial operations to secure the area for Forcible Entry efforts initiating in Phase II. Figure 12 shows the planned approach by CJTF, which includes the help of local coalition Savanna Forces (Marine Corps Warfighting Laboratory 2012).

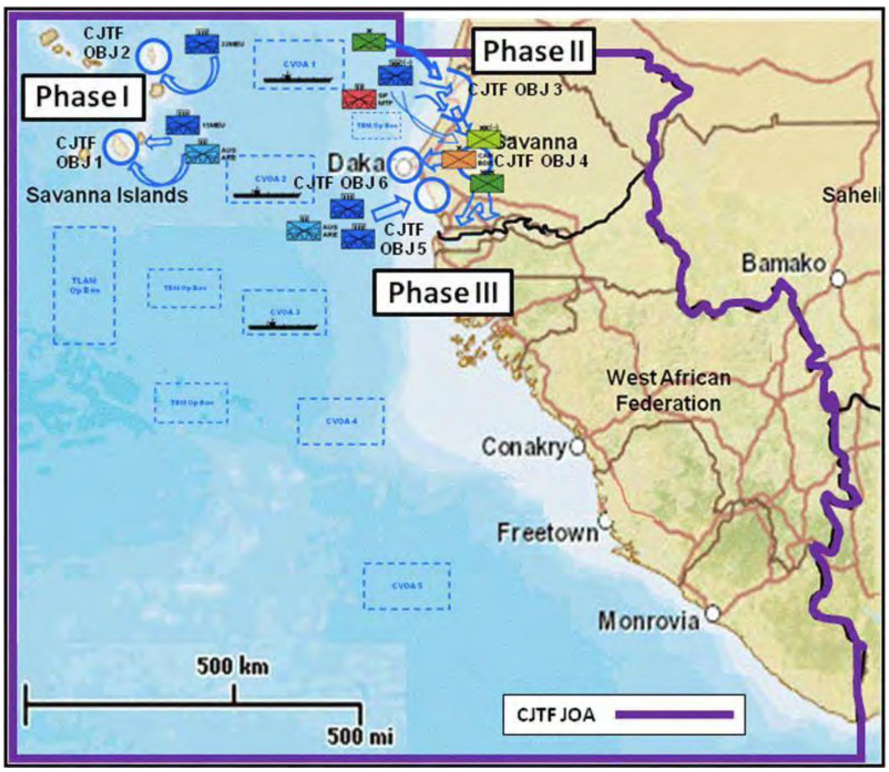


Figure 12. CJTF/Coalition Force Movement (from Marine Corps Warfighting Laboratory 2012)

After forces arrived, the following five objectives were completed. A key assumption on completion was that sufficient forces remained in place to support Phase II without any delay or requirement to request assistance for additional forces (Marine Corps Warfighting Laboratory 2012).

- Neutralize A2/AD Capabilities
- Gain Maritime and Air Superiority

- Protect and Reinforce Savanna Government Forces
- Seize Advance Bases in the Savanna Islands
- Set Conditions for Entry Operations

2. Phase II: Gain Entry: Forcible Entry Efforts

Phase II considers the Forcible Entry efforts associated with the CJTF response. In this phase, CJTF forces move inland with assistance from local Savanna, and coalition forces in order to attack targets of strategic importance. The following objectives were completed by the end of Phase II. As part of the scenario it is assumed that sufficient forces remain in place to support Phase III without any delay or requirement to request assistance for additional forces (Marine Corps Warfighting Laboratory 2012).

- Seizure of a Lodgment
- Rapid Introduction of Joint and Combined Forces
- Attack to Secure the City of Touba
- Continued Expansion of APODS and SPODS in the Savanna Islands.

3. Phase III: Follow-on Operations

In Phase III, CJTF Savanna has completed all prior objectives and is now ready to conduct follow-on operations. The following list comprises the main objectives of Phase III. Phase III evolution is sequential such that objectives listed below must be accomplish in order. Dakar objectives are assumed to be complete with forces remaining in place prior to execution of "Support Follow-on Operations," the vignette of interest for the energy study (Marine Corps Warfighting Laboratory 2012, 9).

- Isolate the enemy-held capital city of Dakar
- Facilitate Savanna Force's Re-taking of Dakar
- Support Follow-on Operations
- Begin Preparations for Transitioning the Battle space for Extended Ground Operations

d. Phase III Vignette Context Development

Figure 13 depicts the decomposition of "Support Follow-on Operations" into three vignettes (Marine Corps Warfighting Laboratory 2012, 9). The vignettes represent three of the potential missions that have been created to address the research questions and provide additional analysis for future research. Vignettes 1 and 2 provide potential mission scenarios that would immediately precede the insertion of Marines into Barra in Vignette 3. Barra is considered of tactical importance to the operation because it is both a border and a port city. It is assumed that Vignettes 1 and 2 have been completed and now serve as preset conditions that are used as stepping stones for Vignette 3.

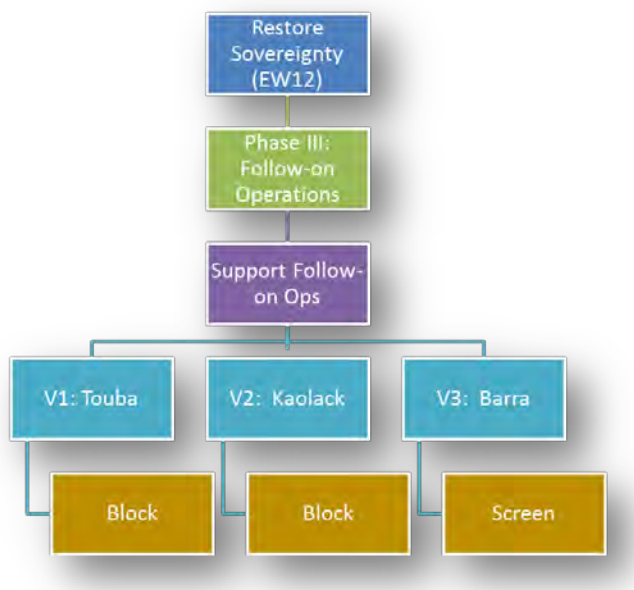


Figure 13. CJTF Expanded Support of Follow-on Operations

1. Vignette 1 – Marine Force Support of Touba

Objective: Vignette 1 entails the movement of a subset of the Marine forces that are currently located aboard ship off the coast of Dakar and forces that are currently located in Dakar to Objective Area-Touba (OA-Touba)—an interior city in the Savanna Territory. Upon reaching OA-Touba Marine forces were required to block enemy forces.

- **Block:** Units assigned to this task may have to retain terrain.

> To deny the enemy access to a given area or to prevent enemy advance in a given direction or on an avenue of approach, it may be for a specified time. (United States Marine Corps 2011)

- **Geographical Data** (Google Maps 2014):
  - Distance 181 km (112 miles):
  - Time from Dakar via convoy: Approximately two hours 43 minutes (Average speed 41 mph)

Mission Intent: After the initial forcible entry efforts in Phases II of EW12, it became necessary to move additional Marines to provide assistance to local Savanna militant forces in Touba. A subset of the force at Dakar designated a SPMAGTF and consisting of a Battalion of Marines, transitioned via MV-22, CH-53, and/or ground convoy to Touba. Once the SPMAGTF arrives in Touba their primary mission will be to Block any enemy WAF movements further into the Savanna Territory.

Depending on the causalities sustained in Phases I and II, and assuming sufficient forces remain in place to move forward with the next objective without any delay/requirement to request assistance from additional forces, Vignette 1 could be completed in conjunction with Vignette 2 –which is described as follows.

2. Vignette 2 – Marine Force Support of Kaolack

Objective: Vignette 2 involves the movement of a subset of the Marine forces that are currently located aboard ship off the coast of Dakar and forces that are currently located in Dakar to Objective Area (OA)-Kaolack—an interior city in the Savanna Territory. Upon reaching OA-Kaolack Marine forces were required to block enemy forces.

- **Block:** Units assigned to this task may have to retain terrain.

> To deny the enemy access to a given area or to prevent enemy advance in a given direction or on an avenue of approach, it may be for a specified time. (United States Marine Corps 2011)

- **Geographical Data** (Google Maps 2014) :
  - Distance 175 km (108 miles):

- Time from Dakar via convoy: Approximately two hours 25 minutes (Average speed 45 mph)

Mission Intent: As previously stated, Vignette 2 could be conducted before, during, or after Vignette 1, but it is assumed, at the time Vignette 2 starts, that Savanna Forces have gained control of Kaolack. WAF forces continue to threaten the Eastern and Southern borders. CJTF Savanna sends a SPMAGTF to Kaolack to secure the city and to provide block functions. The SPMAGTF at Kaolack will secure the city as a waypoint for supply convoys and troop movement south into Barra and further to the East to secure river crossings between Savanna and WAF near Farafenni.

Depending on the causalities sustained in the previous phases and vignettes and the attainment of objectives, and assuming sufficient forces remain in place to move forward with the next objective without any delay/requirement to request assistance from additional forces, Vignette 3 may commence. Vignette 3 represents the team's selection for modeling. Therefore, the details of this vignette have been compiled into the separate section, which follows.

4. Phase III Vignette 3 Detailed Mission Development

Scope: Vignette 3 provides a considerable amount of mission detail all of which could not be modeled by the team due to time constraints. The evolution of Vignette 3 begins with broad considerations and continues to narrow the focus until a segment specification was determined which the team deemed possible to model.

Objective: Vignette 3 entails the movement of a subset of the Marine forces that are currently located aboard ship off the coast of Dakar or located in Dakar to OA-Barra—a port/coastal city in the Southern Savanna Territory. Upon reaching OA-Barra Marine Forces were required to screen until relieved by replacement forces.

a. Tactical Task (Screen)

To observe, identify, and report information and only fight in self-protection. (United States Marine Corps 2011)

b. Geographical Data

(Google Maps 2014):

1. Convoy Distance:
   - Dakar to Kaolack: 175 km (108 miles)
   - Kaolack to Barra: 111 km (70 miles)
2. Flight Distance:
   - Dakar to Kaolack: 166 km (103 miles); Time: Approximately 36 minutes (Average speed 170 mph)
3. Location of Sea based assets: coordinates (14.346741, -17.526789)
4. Time via ground: Approximately four hours 10 minutes (Average speed 43 mph)

c. Force Composition

The initial force inserted consisted of the SPMAGTF including 164 Marines. Insertion was via four Osprey MV-22 Aircraft.

- 4 Platoons – 41 Marines Each (includes two Medical Corpsman)
  - A41: Alpha Company (1st Battalion (BN)), Weapons Platoon, Machine Gun (MG) Section
  - 611: Weapons Company (1st BN, Heavy Machine Gun (HMG) platoon, 1st section)
  - B13: Bravo Battery 1st BN, 3rd Firing Squad
  - 718: Weapons Company (1st BN, 81 mm Mortar Platoon)

d. Vignette Timeline

1. SPMAGTF and equipment maneuvers from Dakar to OA-Barra to screen area.
2. SPMAGTF and equipment are inserted into various locations in Barra as shown by Figure 15 using four MV-22 Osprey aircraft.
3. Each platoon maneuvers to designated area as shown in Figure 16.

4. Platoons perform daily patrols and relay intelligence to CO.

5. During daily routines various FSM forces harass SPMAGTF platoons at random points throughout Barra and neighboring cities.

6. After onset of contact with each harassing force, platoon leaders call for resupply of munitions and medical supplies.

e. Assumptions

The following assumptions are listed to provide an overall understanding of the state of the CJTF before the start of Vignette 3.

1. Definition of a company (1st Company)

    - 1st Company can range from three to five platoons of 41 Marines each.
    - Company brings with it six High Mobility Multi-purpose Wheeled Vehicles (HMMWVs) (four mission HMMWVs and two Ambulance) and other gear associated with its local command element.
    - Initial conditions indicate 1st Company to be made up of four platoons – 164 Marines.
    - Of the 164 Marines in 1st Company, two are Medical Corpsman with associated gear and transportation.

2. Rules of Engagement (ROE) have been defined beforehand.

3. The location of off-shore SBAs is fixed at the beginning of the scenario and does not change.

    - Sea based element is available for launch of Landing Craft Air Cushion (LCAC) for additional methods of Marine insertion and resupply missions.
    - SBAs can also be used to provide support for Call for Fire from both the missile launch and aircraft launch perspective.

4. Air superiority has been established in Phases I and II and continues to maintain presence.

5. Ground Element resupply mission – Kaolack is a secure waypoint, but is not a source of logistics support. Supplies can convoy from Dakar or can be brought by air from Dakar or from sea based element.

f. Insertion Methods

The team considered three methods for the initial insertion of Marines into Barra with the most likely candidates consisting of two air insertion methods each with two options. A third method, which utilizes amphibious assets, is also explored and carries with it several modifications to the preconditions indicated in the vignette assumptions list. Figure 14 depicts the configuration for the three insertion methods.

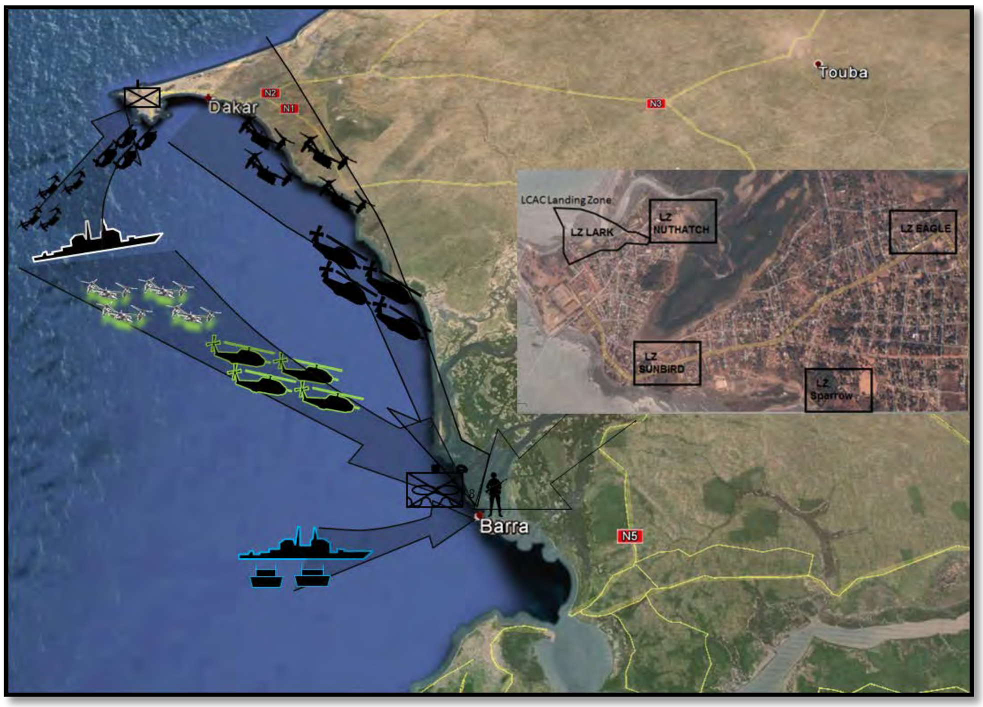


Figure 14. Barra Insertion Methods

1. Method One: Air insertion via Sea based MV-22 to Barra

Option 1: It is assumed for this insertion method that 1st Company has just arrived in theater and is being deployed directly to Barra. 1st Company was inserted via MV-22 directly into Barra. The four MV-22s assigned to 1st Company for insertion depart from the SBAs (approximately 30 miles off shore, with exact coordinates indicated in Figure 14) and fly directly to Barra in order to utilize the four landing zones (LZs) that are depicted in Figure 15. The MV-22s return to the SBAs to pick up Marines until a total of 12 trips have been made (7 trips to insert all Marines, and five trips to bring remaining gear and five HMMWVs (NAVAIR 2014). After the insertion of Marines and equipment the MV-22s return to the SBAs.

Option 2: It is assumed for this insertion method that 1st Company was a part of the initial landing force during Phases I and II and are now being moved to Barra for a new mission. 1st Company was inserted via MV-22 into Barra. The four MV-22s assigned to 1st Company for insertion depart from SBAs (approximately 30 miles off shore) and fly to Dakar to pick up 1st Company. The MV-22s then maneuver to Barra in order to utilize the four LZs that are depicted in Figure 15. The MV-22s returned to Dakar to pick up Marines until a total of 13 trips were made (seven trips to insert all Marines, and six trips to bring remaining gear and six HMMWVs (NAVAIR 2014)). After insertion of all Marines and equipment the MV-22s return to the SBAs.

2. Method Two: Sea based CH-53K to Barra (Company)

Option 1: It is assumed for this insertion method that 1st Company has just arrived in theater and is being deployed directly to Barra. 1st Company was inserted via CH-53K directly into Barra. The four CH-53Ks assigned to 1st Company for insertion depart from SBAs (approximately 30 miles off shore with exact coordinates indicated Figure 14) and fly directly to Barra in order to utilize the four LZs that are depicted in Figure 15. The CH-53K aircrafts return to the SBAs to pick up Marines until a total of nine trips have been made (three trips to insert all Marines, and six trips to bring remaining gear and six HMMWVs (military-today.com 2014)). After insertion of all Marines and equipment the CH-53Ks return to the SBAs.

Option 2: It is assumed for this insertion method that 1st Company was a part of the initial landing force during Phases I and II and are now being moved to Barra for a new mission. 1st Company was inserted via CH-53K into Barra. The four CH-53Ks assigned to 1st Company for insertion depart from SBAs (approximately 30 miles off shore) and fly to Dakar to pick up 1st Company. The CH-53Ks then maneuver to Barra in order to utilize the four LZs that are depicted in Figure 15. The CH-53Ks returned to Dakar to pick up Marines until a total of nine trips were made (three trips to insert all Marines, and six trips to bring remaining gear and six HMMWVs (military-today.com 2014)). After insertion of all Marines and equipment the CH-53Ks return to the SBAs.

3. Method Three: Sea Based LCAC to Barra

It is assumed for this insertion method that 1st Company has just arrived in theater and is being deployed directly to Barra. It is also assumed that a LSD-41 class or other configuration of SBAs has transitioned to the following coordinates (13.720122, -16.948440) off shore from Barra in order to support the insertion of Marines via LCAC (AN LSD-41 can accommodate four LCACs (FAS.org 1999)).

1st Company was inserted via LCAC directly into Barra. The four LCACs assigned to 1st Company for insertion depart from the SBAs (approximately 32 miles off shore from Barra with coordinates: 13.720122, -16.948440) and maneuver directly to Barra in order to utilize the LCAC LZ as depicted in Figure 15. The LCACs return to the SBAs to pick up Marines until a total of eight trips have been made. This includes seven trips to insert all Marines, and one trip to bring remaining gear and six HMMWVs (Defense Industry Daily Staff 2005). After insertion of all Marines and equipment the LCACs return to the SBAs.

g. Landing Zones

Figure 15 depicts air and amphibious landing zones that could be used during the Marine's insertion into Barra. The four air LZs (NUTHATCH, SUNBIRD, SPARROW, and EAGLE) have been identified to provide easy access to various points around Barra, and to allow simultaneous landing to drop off Marines and equipment.

Figure 15 also provides details for an optional LCAC landing zone. If the LCAC insertion method is selected, LZ LARK has been identified as an ideal insertion location. It provides direct access to the city via the north side of the peninsula. There is enough space for all insertion LCACs to land at the same time. The location on the north side of the city provides cover for the Marines from the WAF occupied city of Banjul that is less than three miles to the southwest across the mouth of the river. In the case of insertion via LCAC, it is also likely that resupply missions would also be conducted via LCAC,- and would utilize the same LZ as depicted in the Figure 15.

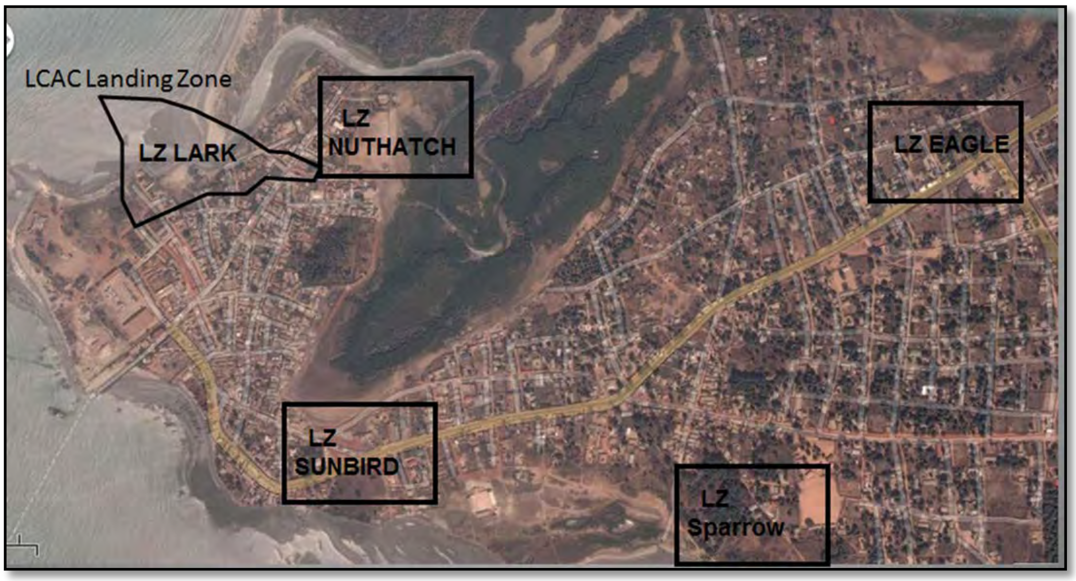


Figure 15. Platoon Insertion Points

h. Organization and Movement

As the Marines were inserted into Barra via the identified LZs in Figure 15, they prepared to maneuver to their designated locations as identified by the icons in Figure 16 (United States Army Training and Doctrine Command 2004). The initial landing of four MV-22s inserted 96 Marines, 24 to each of the four LZs. Upon landing, the Marines at each LZ established a perimeter while debarking and then proceeded to their designated locations as identified in Figure 16. The second round of MV-22 sorties brought the remaining 68 Marines. A final third round of sorties brought the remaining gear and four HMMWVs to be used by 1st Company. For simplicity, the Marines debarking from the MV-22s proceeded to posts in the immediate area surrounding the designated LZ. One of the first positions to be established after the Marines arrived was an Operation Post that was located in the northeast portion of Barra and was designated by the OPS icon in Figure 16.

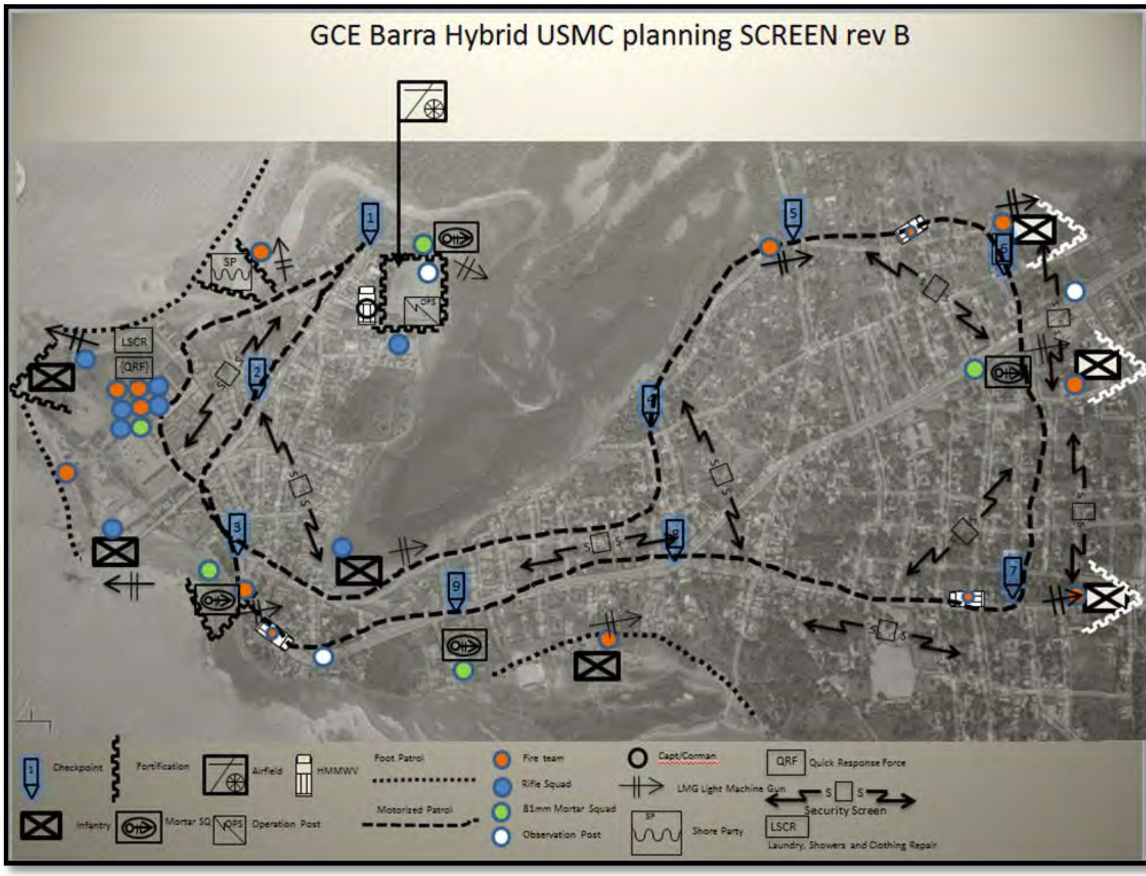


Figure 16. GCE Barra Hybrid USMC Planning

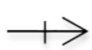
Shortly after the OPS Post was established, the remaining positions on the map were fortified and manned by the Marines with the structure indicated in Table 2.

Table 2. Unit Breakout for Marine Positions

Icon	Unit	Marines / Unit	Locations	Total Marines
	Fire Team (Reinforced)	5	14	70
	Rifle Squad	8	8	64
	81mm Mortar Squad	3	5	15
	Observation Post	4	3	12
	Capt/Corpsman	3	1	3
			Total	**164**

The following Squad Automatic Weapon (SAW) and 81 mm mortar icons on the map depicted the actual weapon/equipment to be setup on location and the primary direction of fire (direction the arrow is pointing). Table 3 provides the map icons and detailed information for the M240B (United States Marine Corps 2014) and 81 mm mortar (United States Marine Corps 2014).

Table 3. Squad Equipment Description

Icon	Equipment Description
	Squad Automatic Weapon (SAW) - M240B is a fully automatic 7.62mm machine gun capable of a sustained rate of fire of 100 rounds/minute. It has a maximum effective range of 1800 metres. In the defensive positions in the figure above, it utilized a tripod to ensure precise fire at long ranges, but can also be mounted on a Humvee for patrol protection purposes.
	81mm Mortar - lightweight portable artillery that is used to provide supressive fire on targets as indicated by supported ground units. The 81mm mortar has a range of 5700 meters and can fire high explosive shells, smoke rounds and illumination rounds.

After all positions were manned and fortified by the appropriate Marines, the Screening operation began. Figure 16 describes the routes patrolled by use of dotted and dashed lines. The dotted lines designate foot patrol routes and were patrolled by fire teams. The foot patrol routes extend along the shore/waterfront areas where motorized patrol is not possible. Table 4 identifies the three primary/secondary weapons the team decided to issue to the Marines. The Marine Corps arsenal is far more extensive, but for simplicity, the Marines in the scenario were issued the M16 (United States Marine Corps 2014), M9 Beretta (United States Marine Corps 2014), and the M249 SAW (United States Marine Corps 2014) as identified in the table.

Table 4. Marine Standard Issue Weapon Systems

Weapon	Weapon Description
M16	The M16 is the primary service rifle for a Marine. It fires a 5.56x45mm round, has a maximum effective range of 550 meters, and a sustained rate of fire of 12-15 rounds/minute. It uses a 30 round magazine and is capable of three-round burst or single-shot semi-automatic firing.
M9 Beretta	The M9 Beretta is a lightweight semi-automatic hand gun that fires a NATO-standard 9mm round. It has a maximum effective range of 50 meters, a 15 round magazine and is a defensive weapon carried by all Marines.
M249 SAW	The M249 SAW is the fireteam's automatic weapon. It produces heavy suppresive fire with the 5.56x45mm round, but is not as heavy as the M240B. It has a sustained rate of fire of 85 rounds/minute, a maximum effective range of 1000 meters, and can accept a variety of ammunition inputs ranging from the 30 round M16 Magazine to a 200 round belt-fed system.
M240B	The M240B provides a heavier, higher rate of fire than the M249 using a 7.62mm round. It has a maximum effective range of 1800 meters and fires at a sustained rate of 100 rounds/minute. The M240B accepts standard belt fed ammunition.

Every Marine is issued an M16 and M9 Beretta, but for fire team roles, one team member substitutes an M249 SAW for the M16. Marines also bring with them two full magazines/boxes of ammunition for each weapon carried. For the purposes of the mission scenario, the team deviated from the standard definition of a fire team (three to four members) and added a fifth member (United States Marine Corps 2002). This additional member constitutes a reinforced fire team. The addition of the fifth member made it easier to designate a particular fire team responsible for motorized patrols, as each HMMWV in the scenario contained five Marines, without making Marines cross fire teams.

The dashed lines that map a route around the city depict the designated motorized patrol. At any given moment there were three HMMWVs with fire teams patrolling the city. In a vehicular configuration, the team described a fire team as a driver, three passengers, and a gunner that manned a M240 mounted to the top of the HMMWV (United States Marine Corps 2014). The motorized patrols will follow the designated route throughout the city passing through each of the identified checkpoints.

In addition to the Marines stationed around the city and the Marines on patrol, the fourth platoon of Marines were located in the laundry, shower, and clothing repair (LSCR), which is located on the far west side of Barra. This group of Marines is on rest and provides the capability for a Quick Reaction Force (QRF). The QRF is a group of Marines that can respond in a moment's notice to a crisis that erupts throughout the city (United States Marine Corps 2014). During the normal course of events, each platoon will rotate through patrols and stations and then back to a resting posture. This provides the opportunity for Marines to rest, shower, eat, clean gear and weapons, and replenish supplies to prepare for the next round of patrols.

i. Threat Understanding

Prior to the insertion of 1st Company intelligence indicated the potential for minor pockets of FSM resistance throughout the city. 1st Company's mission is to maneuver to Barra in order to Screen, or observe, identify and report information back to CE and only fight in self-protection and according to the ROE. The ROE are used to distinguish differences in the way forces are required to engage the enemy based on what part of the mission is executed. As a part of this mission 1st Company is required to determine if there are additional large pockets of WAF resistance remaining in the city, or if the threat mainly consists of FSM that is capable of small harassing attacks. In addition to the potential threat, there also exist a large number of neutral civilians that inhabit the area. According to the ROE, neutrals are to be treated as non-hostiles and are not to be engaged unless provoked to the point of endangerment.

j. Engagements

Various engagements had potential to occur during the screen operation by the Marines. As the Marines maneuvered from checkpoint to checkpoint the possibility of encountering FSM resistance increased. During the engagements certain areas had the potential to receive indirect fire help from the mortar teams located throughout the city (i.e., assuming the engagement was not near any large groups of buildings/houses deemed off limits for fire support). If deemed appropriate, the team on the ground being engaged by the enemy could call in coordinates for mortar fire assistance.

Other cover/suppressive fire assistance could be accomplished by the use of the SAW. With a long range and high rate of fire the SAW has the ability to suppress enemy fire or halt an advance in position. In both situations the ROE changed and the Marines encountered a threat that needed to be defeated in order to maintain position, or provide relief in order to maneuver to better positions during the engagement.

k. Sustainment

During the course of the standard mission, it is a known fact that the Marines need to be resupplied with items such as food, water, ammunition, and medical supplies. For the given scenario, and remaining consistent with EF21 concepts, the SPMAGTF – 1st Company – brings with them at least three days of supplies / days of ammunition (DOS/DOA) (United States Marine Corps 2014). The following assumptions establish a baseline for 1st Company in terms of supplies and their use / Logistics and Material supply Request (LOGMAT).

- 1st Company brings with them three DOS/DOA
- As soon as enemy force is engaged CO requests supply of ammunition
- Regular schedule of supply is every three days

There are three main methods for logistical supplies. The supplies may be brought via air, land, or sea. Given the initial conditions and the location of Barra relative to Dakar and the SBAs waiting off shore, the most likely scenario for resupply is via air asset, followed by ground convoy, and finally via sea transport.

Air supply sorties have the option of being flown in directly from the off shore assets or from Dakar. As mentioned previously, Kaolack, a waypoint via ground to Barra, is under CJTF control but has not been established as a source of logistical supply. In the event that supplies are called for due to conflict with enemy forces, an air supply sortie will be conducted as soon as possible via MV-22 or CH-53K. Regularly scheduled supply sorties (one shipment every three days) will also be conducted via MV-22 or CH-53K and will likely include the following:

1. 500 Gallons Potable Water
2. 500 Gallons JP-8
3. Ammunition (requested amounts/caliber)
   - 9mm
   - 5.56x45 mm
   - 7.62 mm
   - 81 mm mortar
4. Medical Supplies

In a given conflict it could become necessary to convoy materials/supplies via ground due to lack of availability of aircraft, inclement sea-state/weather, or other factors that would prohibit sorties during a scheduled or unscheduled supply operation. In this type of scenario a convoy would leave from Dakar and travel via road through Kaolack and down into Barra. The aforementioned convoy would likely consist of the following vehicles/supplies:

1. Combined Anti-Armor Team (CAAT) – Lead HMMWV (Global Security 2014)
2. CO/COMMs – second HMMWV
3. Logistics Vehicle System Replacement (LVSR) 1–500 gallons H2O (Global Security 2014)
4. LVSR 2–500 gallons JP-8 (Fuel) (Global Security 2014)
5. Ambulance – HMMWV

6. Squad – HMMWV

7. CAAT –Trailing HMMWV (Global Security 2014)

The final possibility for logistical supply involves the use of LCACs If a sea-based logistical supply effort was to be attempted, it would require a precondition. This precondition involves the movement of a SBA, with the ability to support an LCAC, to a location approximately 32 miles off the coast of Barra (Coordinates: 13.720122, -16.948440). The movement of this asset down from its original location off the coast of Dakar would shorten the trip for the LCAC from over 87 miles down to the specified 32 miles. With the SBA in place, a single LCAC could bring all required supplies to the Marines in Barra.

l. Scalability

The initial determination for the scale of troop insertion is based on the COs assessment of the area in the planning stages of the mission. Characteristics such as the perceived threat, area, size, location, geography, and infrastructure are considered. If the initial assessment of the area indicates a smaller enemy threat presence, a smaller initial force can be sent. If initial assessment indicates the opposite, then a larger force can be sent. 1st Company is able to be scaled from anywhere between 123 and 205 Marines (three to five platoons of 41 Marines each). A smaller scale 1st company will require less logistical support during the mission but will also have a decreased ability to retain terrain, decreased firepower and an overall smaller presence in the area. A larger scale 1st Company will have the opposite.

If, after an initial Marine force has been inserted, it is determined that the actual threat is larger or smaller than originally perceived, the CO can scale up or scale back depending on the condition in the area. In addition to the initial intelligence, the information 1st Company provides back to the CO will provide a better picture of the battle space moving forward.

m. Rules of Engagement

In times of war it is necessary to maintain order on the battlefield. As such the following "Rules of Engagement" (Figure 17) have been extracted from the *Operational Law Handbook 2014*. They provide the basic responsibilities for soldiers in wartime (Bahm et al. 2014).

II. SOLDIER'S GENERAL RESPONSIBILITIES IN WARTIME

A. Carry out all lawful orders promptly and aggressively.

B. In rare cases when an order seems unlawful, do not carry it out right away, but do not ignore it either. Instead, immediately and respectfully seek clarification of that order. "Sir/Ma'am, are you ordering me to ______?"

1. Soldiers may be held criminally responsible for unlawful acts they personally commit in time of war. There is no "statute of limitations" on prosecution of war crimes, so Soldiers may be prosecuted years later.
2. If a Soldier is court-martialed for carrying out an obviously unlawful order, the "I just followed orders" defense usually fails. By training and common sense, Soldiers must recognize unlawful orders and act appropriately.

C. Know:

1. The Soldier's Rules.
2. Forbidden targets, tactics, and techniques. (See related material above).
3. Rules regarding captured soldiers.
4. Rules for the protection of civilians and private property. (See related material above).
5. Obligations to prevent and report LOAC violations.

III. THE SOLDIER'S RULES

A. Fight only enemy combatants.

B. Do not harm enemies who surrender — disarm them and turn them over to your superior.

C. Do not kill or torture EPW, or other detainees.

D. Collect and care for the wounded, whether friend or foe.

E. Do not attack medical personnel, facilities, or equipment.

F. Destroy no more than the mission requires.

G. Treat all civilians humanely.

H. Do not steal — respect private property and possessions.

I. Do your best to prevent violations of the law of armed conflict

J. Report all violations to your superior.

Figure 17. Rules of Engagement (from Bahm et al. 2014)

n. Spiral Application and Methodology

Three incremental levels of the operational concept were specified to allow subsequent spiral development in accordance with time available to the team. The increments include the following and are specified in detail herein.

- QRF Fires Engagement
- Barra Screening Operation
- Barra Insertion

o. Modeled Segment Specification Spiral One

After establishing a baseline understanding for Vignette 3, it was necessary to focus on the key drivers of energy and effectiveness of the mission. The screening operation remains status quo and very predictable until something of significance occurs, such as an enemy engagement. It is only after a change to the norm that the scenario becomes interesting and energy efficiencies and effectiveness are demonstrated.

In order to analyze a mission which presented opportunity for energy and effectiveness demonstration, a specific battle scenario was conceived. Battle engagement, along with all the sustaining elements that are necessary, affords the modeling team opportunity to employ several techniques to expose the operational energy / operational effectiveness relationship.

In this iteration of the engagement a Marine patrol consisting of three HMMWVs is assumed to have driven along a predetermined route through the greater Barra area and has now come across a large compound. Each HMMWV is occupied by one of three Fire Teams that has been assigned to the mission. The 15-Marine team (five Marines per Fire Team) is then ambushed just outside this compound west of Checkpoint 7 (Figure 18). The FSM (100 militia) appear to be protecting a large, previously unknown compound likely used for drug trafficking. Elements of the enemy force attack the convoy as it approaches.

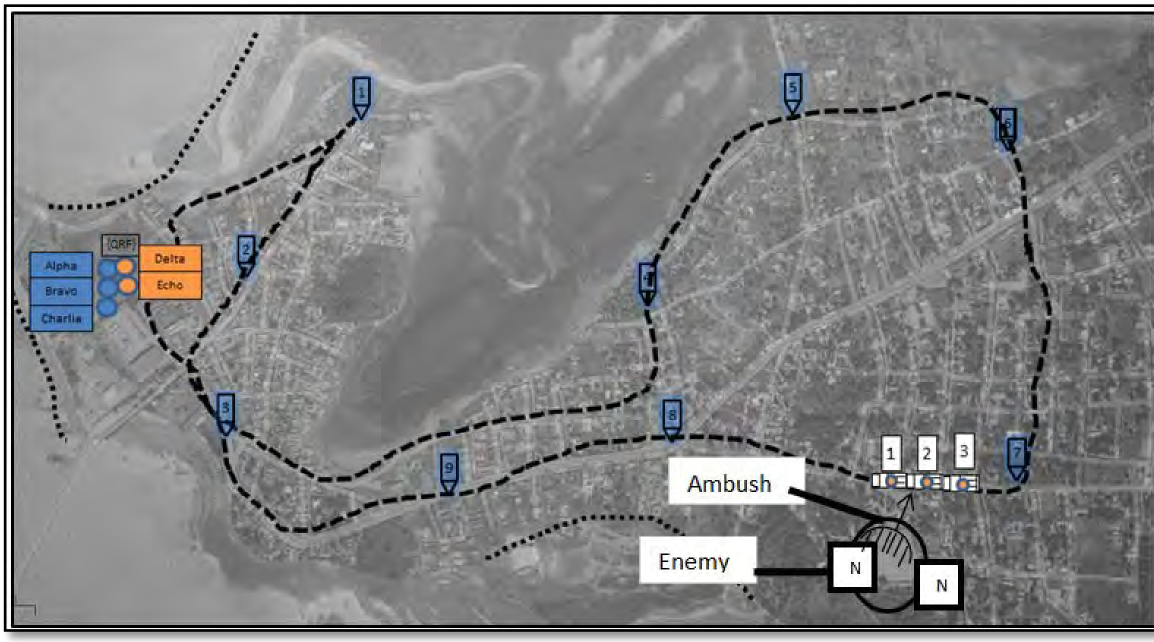


Figure 18. Barra Map – Spiral One

As soon as the battle ensued, the Marine Patrol gave SALUTE (Size, Activity, Location, Unit, Time, and Equipment) to the CO who coordinated for assistance from the QRF, located on the far west side of Barra. The QRF, consisting of 34 Marines, was picked up by a CH-53K and flown to an LZ southwest of the engagement. Upon insertion, the QRF maneuvered to the battle location and engaged the enemy (Figure 19). To demonstrate both a realistic battle engagement and operational energy use the scenario includes Close Air Support (CAS) from a sea based AH-1Z Viper attack helicopter. Air logistics consists of MV-22 re-supply, and casualty evacuation to the sea base.

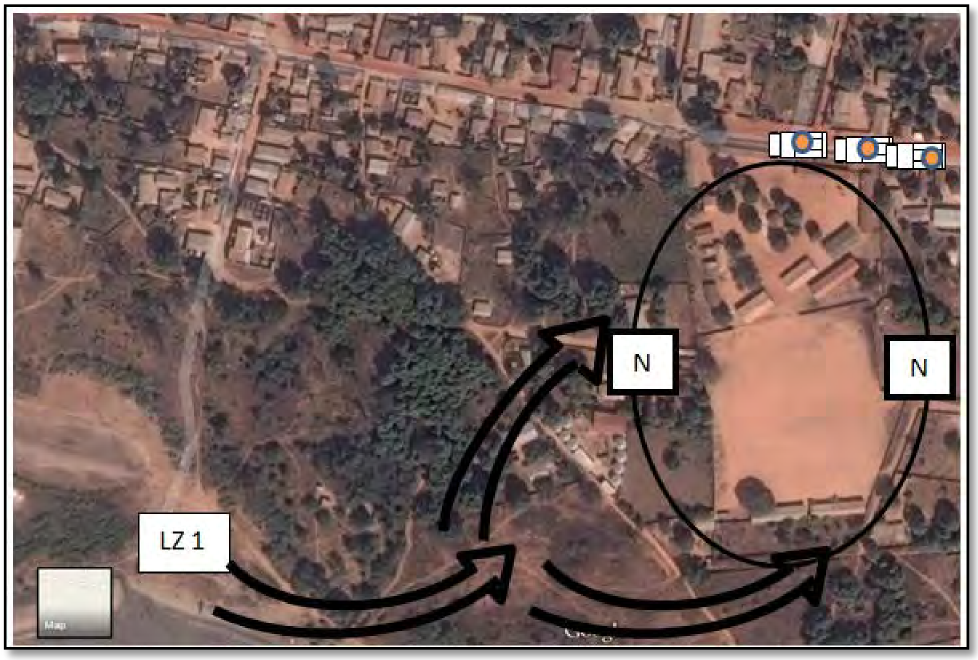


Figure 19. Spiral-One Scenario 1 – QRF Insertion

In order to appropriately model the effect force size had on efficiency and effectiveness, two additional scenarios were created that featured larger QRF and patrol forces. In the second scenario (Figure 20), it is assumed that the QRF size has increased from 34 Marines to 50 Marines. The QRF now also brings with it a mortar squad for possibility of increased suppressive and indirect-fire. With the addition of 16 more Marines, the air assets that bring the QRF to the fight also have to increase. In the second scenario both an MV-22 and a CH-53K are responsible for transporting the QRF from Barra to the engagement. This created the need for a second LZ southwest of the engagement and made for longer insertion times and distances being traversed by the QRF. CAS and logistics support elements are assumed to be the same as in Spiral 1 Scenario 1.

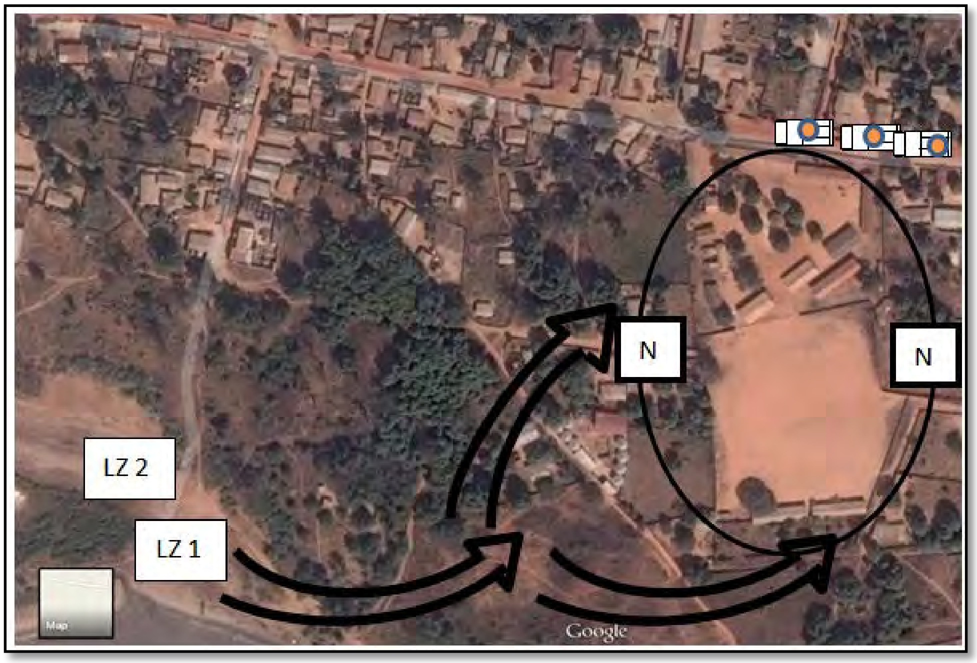


Figure 20. Spiral-One Scenario 2 – QRF Insertion

Finally, the third scenario of Spiral-One (Figure 21) brought with it yet another increase in the size of the QRF (79 Marines total), and an increase in the air assets. The increase in the QRF added another Mortar Squad and 26 other Marines that were able to respond to the engagement. In order to move the 79 Marines to the engagement, two CH-53Ks and one MV-22 were required. The extra air asset also required an additional landing zone, which yet again increased the time required for the insertion and the distance the Marines had to travel to get to the engagement after being dropped off. The maximum distance traveled by the Marines was less than 1500 meters. CAS and logistics support elements are assumed to be the same as in Spiral 1 Scenario 1.

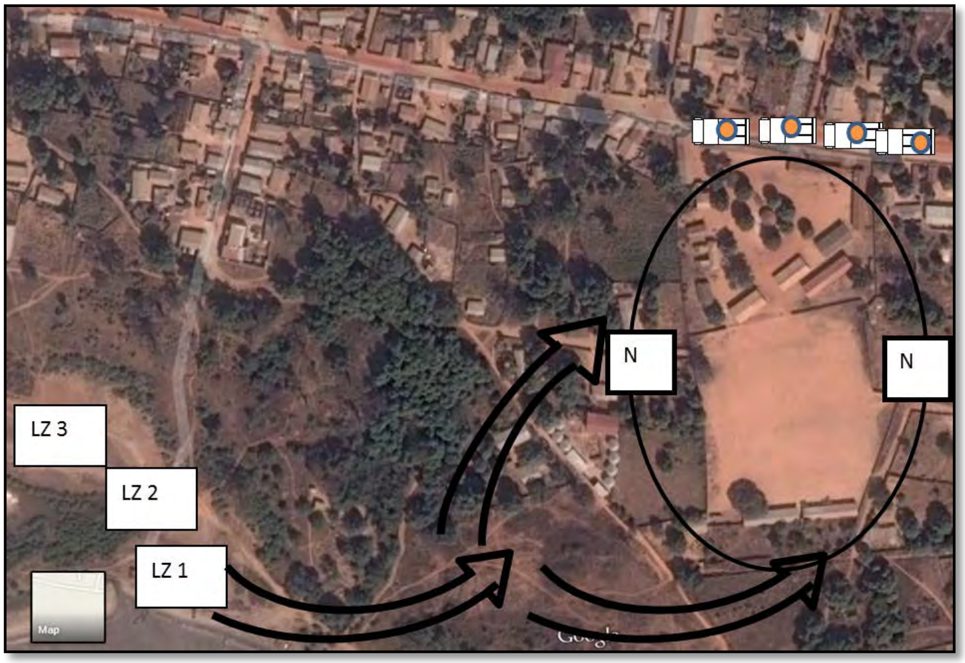


Figure 21. Spiral-One Scenario 3 – QRF Insertion

p. *Modeled Segment Specification Spirals Two and Three*

The intent of Spiral 2 would be to add the peripheral Marines to the scenario in addition to Marines already employed in Spiral 1. For Spiral 2 one would add all of the Marines at all of the checkpoints/posts around the city as described in Figure 21. At this point all of the Marines would still be "immobile" in that they do not move for patrol or move to engage enemy militia that are attacking in various other parts of the city. The Marines at the posts only respond to engagements at their positions, should they exist. Only the QRF will respond to the major enemy engagements. Spiral 2 will also add smaller enemy engagements at various posts around the city. These small harassing attacks would not be large enough to warrant action by the QRF (only four or five FSM soldiers), but would be large enough to possibly trigger the need for additional ammunition to be brought to them, thus potentially triggering additional supply sorties. While Spiral-2 would set the conditions for a more "life-like" scenario and would help paint the picture of why the Marines were there to begin with, Spiral-3 would complete the entire picture.

In Spiral-3 the scenario would utilize the same position information for each of the Marines in Spiral-2 in addition to including the insertion phase. The Marines would arrive from the SBAs off-shore, debark from the air assets, and then maneuver via a prescribed path to each Marine's position on the map. Once each Marine is in position, the Fire Teams in each of the patrol HMMWVs would begin their patrol. They would follow the checkpoints around the city until they reach the "ambush" area next to Checkpoint 7. At this time the engagement would begin, the QRF would respond as normal and the rest of the engagement would proceed.

In certain iterations within Spiral-3, there will be enough additional assets at posts throughout the city so that those assets closer to the engagement can respond to the ambush on the patrol as well. An additional variation could include the fire team (located at Checkpoint 7) coming to the aid of the patrol convoy, long before the QRF arrives to see the impact additional Marines earlier in the fight would have on the outcome.

q. Sea-Based Scenarios

In addition to the largely land based scenarios and vignettes discussed in this section, there also exists a significant sea based scenario that has not been explored in its entirety. During Operation Restore Sovereignty a large fleet of Marine ships waits off the West African Coast (Marine Corps Warfighting Laboratory 2012). In accordance with Marine Corp doctrine, SBAs are required to provide coverage of the entire battle space with the capabilities they possess. They have the ability to provide radar coverage, missile strike abilities, platforms for air and sea assets from which to debark, and are also a source of logistical supplies for the Marines located in country (United States Marine Corps 2014).

It is highly likely that a portion of the sea assets would maneuver from their initial locations off the coast of Dakar and would transition to an area closer to Barra in order to provide greater support. Future iterations of Vignette 3 could be expanded to include such maneuvers. These changes in placement of SBAs would greatly change the Marine's posture. It would allow additional avenues of troop and equipment insertion, it would provide localized Points of Debarkation (PODS) for both sea and air assets, and would provide quicker responses to battlefield crisis should the situation arise. In many of the scenarios listed the team has identified insertion methods and supply operations that would utilize such relocations of SBAs, but the analysis has not been expanded to fully encompass the differences experienced with the change in location.

E. CHAPTER SUMMARY

The SE process was divided into detailed process steps necessary to support execution. Process steps included needs refinement, requirements analysis, mission analysis, specification of system function and form, modeling, and AoA.

The need statement was refined through a process of subjecting the primitive need statement and overarching objective to stakeholder analysis. The stakeholder identification established in Chapter I was elaborated to form a detailed stakeholder analysis, which served to influence the balanced statement of effective need for the trade study. A key finding regarding the effective need was that the research should expose the relationship between operational energy and operational effectiveness in a balanced manner to support realignment of the fast, austere, and lethality objectives of the USMC.

High level requirements were established to guide the specification of a notional system and operational scenario development which would support a prediction of effectiveness. An effective system must be capable of performing a full range of military functionality across the six war fighting functions, and the system must be energy efficient. Energy efficiency is considered the independent variable in the study. The system must be scalable both functionally and physically based on USMC doctrine. Requirements for scenario development include the following. The research should utilize MSBE to create the performance prediction that informs the understanding of the tradespace. Title 10 War Games should be used to demonstrate extensibility of existing research. Operational concept development should be robust enough to support objectives of this capstone research and future research as well capability gap re-assessment.

The Mission analysis and operational concept development explored a Title 10 War Games evolution (EW12). The mission Restore Sovereignty was decomposed and a phase selected for concept development. The team bounded and specified the operational concept of Phase III (Follow on Operations) into vignettes which would support options for MBSE development. The team selected Vignette 3, a screen operation at the port city of Barra, for detailed development. The Barra operation was further broken down into insertion methods, screening setup, and a battle engagement scenario. The team produced three operational scale levels at Barra for supporting the research questions. Guidance was provided for spiral representation of the Barra operations starting with the minimum battle engagement, and ending with the full end to end vignette representation. The so called "Spiral One Modeled Segment Specification" was determined to be the focus for specification to the modeling team.

III. SYSTEMS ENGINEERING – PART II

A. INTRODUCTION

Chapter II produced an operational scenario, traced to an overarching mission context, and bounded by detailed vignette descriptions. The next step in the evolution of this capstone project was to specify the form and function of a notional system that would accomplish the objectives of the specified vignette; and to specify the MOEs which would allow the measurement of attaining that objective. This chapter provides the detailed form, function, and MOE development necessary to complete the SE process.

B. MODELED SEGMENT SPECIFICATION

1. Functional Hierarchy

The team created a functional hierarchy that represented the complete specification of the functional capability of the modeled segment developed in the mission analysis of Chapter II.D.4.n. Buede (2009) defines functional architecture as follows.

> Functional Architecture: (a) logical architecture that defines what the system must do, a decomposition of the system's top-level function. This very limited definition of the functional architecture is the most common and represented as a directed tree.

The required functions were determined by examination of the Marine Corps doctrinally established tasking in context with the mission scenario developed (United States Marine Corps 2014). A functional hierarchy was then implied by tracing the low level functions back up to the appropriate warfighting function. Figure 22 depicts the notional functional hierarchy necessary to support the modeled segment specification (Operation Restore Sovereignty, Phase III, Vignette 3, modeled segment, spiral one). The detailed functional hierarchy for each war fighting function is provided in Appendix C. Refer to Appendix A for war fighting function definitions and Appendix B for Marine Corp Tasks selected for the modeled segment.

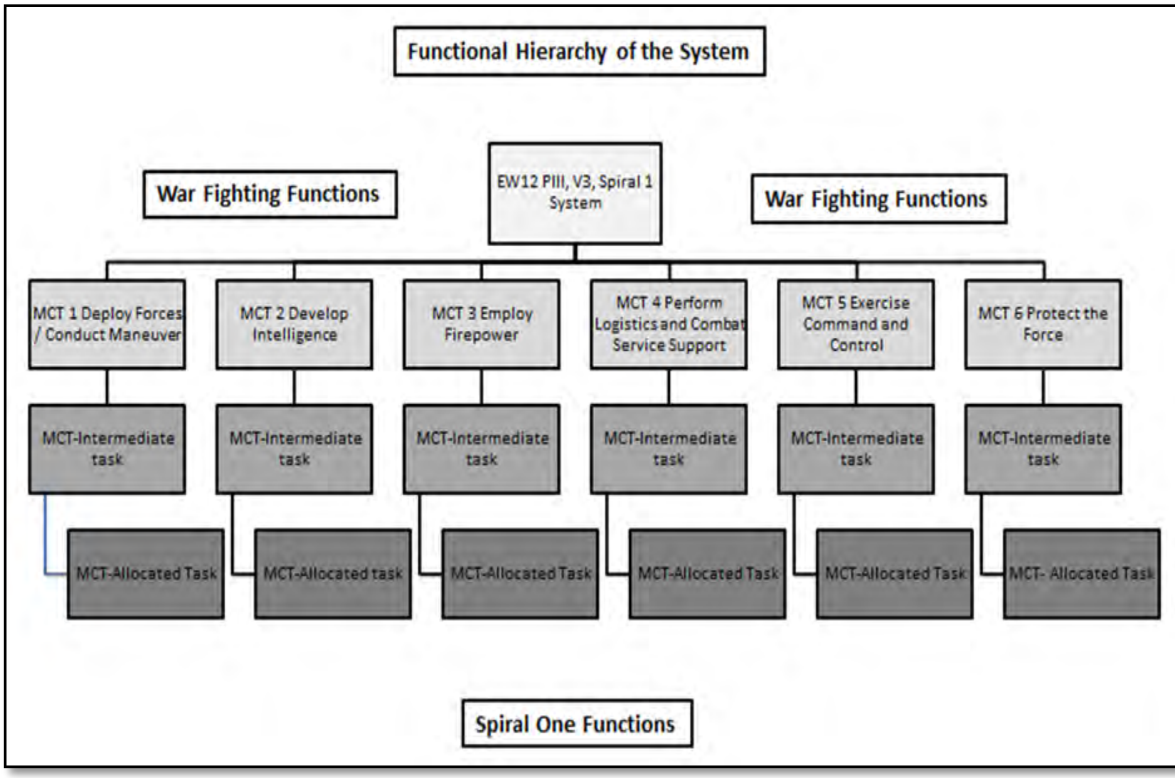


Figure 22. Functional Hierarchy Marine Corp Tasks (MCTs) (after United States Marine Corps 2014)

The fourteen MCTs which are shown at the bottom of Figure 22 represent the key functionality of the system which is to be modeled. This functionality is described in the sections below in terms of the relationship to the system functionality required to support the specified modeled segment. All tasks in this section a - f are taken from the Marine Corps Task List and represent correct USMC task taxonomy for the representation of the system function (United States Marine Corps 2014).

a. MCT 1 Deploy Forces / Conduct Maneuver

1. MCT 1.3.4.1.1 Conduct Airborne Rapid Insertion/Extraction

This task is used to remove active (non-injured) Marines from the Barra battle area. The task employs both CH-53K and MV-22 assets called in from the sea base for post mission activity.

2. MCT 1.6.5.11 Conduct Quick Reaction Force Operations

The QRF operations include the movement of the QRF forces defined in Chapter II.D.4.n to the battle zone. Three scenarios are defined with increasing QRF scale and consequently increased requirements for this maneuver operation. The QRF is required to arrive in 15 minutes or less. The movement is accomplished by air insertion through the use of MV-22 and CH-53K assets.

3. MCT 1.6.11.3 Conduct Screen Operations

Screen operations include the initial convoy operation as described in Chapter II.D.4.n. A convoy of HMMVWs performs the screen and encounters the enemy. The initial observation of the enemy by the screening convoy results in a SALUTE to command which initiates Command, Control, and Communication (C3) coordination for the QRF response. The convoy maintains a defensive posture while observing the enemy until the QRF support arrives. Three scenarios are defined with different convoy sizes and composition as defined in Chapter III.B.2. Screening is accomplished through the use of the HMMWVs, observation gear (sensors), and communication equipment.

b. MCT 2 Develop Intelligence

1. MCT 2.1.1.5 Support Targeting

Targeting is supported through the acquisition and identification of targeting information which may include details about the target attributes that allow effective engagement. Targeting support is provided by the sensing capability in the battle space as defined in Chapter II.E.2.b. Targeting support is a necessary element to successful implementation of MCT 3.2.4.2 (Conduct Indirect Fires).

2. MCT 2.1.1.6 Support Combat Assessment

Combat assessment is facilitated by collection and dissemination of battle space information regarding the overall effectiveness of the operation. The modeled scenario is concerned in particular with Battle Damage Assessment (BDA), which provides key information about the consequences of the engagement progression. In the modeled scenario, BDA is accomplished through the platoon leaders' communication of the situation on the ground with the commanding officer. Communication gear supports this determination.

c. MCT 3 Employ Firepower

1. MCT 3.2.3.1.1 Conduct Close Air Support

Conduct CAS consists of aircraft direct fires and is provided with the QRF insertion via the AH-1Z Viper attack helicopter for each of the three configurations. The AH-1Z sorties support ground forces for the duration of the battle engagement. AH-1Z brings significant firepower as defined in Chapter III.B.2.b.

2. MCT 3.2.4.1 Conduct Direct Fires

Direct fires consists of all fires operations (other than CAS) which engage the target at the platform level and without off platform targeting support. This includes ground based fires operations in the modeled scenario which are conducted by the riflemen and any infantry hand gun, machine gun or HMMVW mounted machine guns. Chapter III.B.2.b details the configuration of this gear.

3. MCT 3.2.4.2 Conduct Indirect Fires

Indirect fires for the modeled scenario consists of mortar squad fires operations. The targeting information is provided externally to the mortar platform by observers in the battle space supporting targeting with sensing and command and control (C2) capabilities. Mortar squad capabilities are defined in Chapter III.B.2.b.

d. MCT 4 Perform Logistics and Combat Service Support

1. MCT 4.3.8 Conduct Air Logistic Support

Air logistics in the modeled scenario consists of re-supply to the battle space and is supported by MV-22 sorties. Air logistics is intended to support ammo, fuel, and other consumables necessary for the conduct of the battle. Sortie rates are determined by the duration and intensity of the engagement.

2. MCT 4.5.5 Conduct Casualty Evacuation

Casualty evacuation is supported by medical CH-53K helicopter sorties. Sortie rates are determined through BDA which is dependent on the intensity, length, and success in the battle engagement. The medical CH-53K is also employed for casualty evacuation in the post engagement period.

e. MCT 5 Exercise Command and Control

1. MCT 5.3.1.2 Exercise Tactical Command and Control

Tactical C2 is supported through the communications systems and situational awareness of the battle space. In the modeled segment specification, this supports the command sequence to provide a QRF support to the battle.

2. MCT 5.3.4.4 Coordinate Ground Surface Fires

Coordination of ground fires is supported through communications systems and situational awareness including targeting information. In the modeled segment specification the C2 fires sequence is necessary for indirect fires operations. Direct fires have no special C2 sequencing in the modeled segment.

3. MCT 5.3.4.5 Coordinate Close Air Support

Coordination of CAS is accomplished through communications systems and battle space SA. In the modeled segment specification CAS coordination involves the C2 sequence from the initial convoy SALUTE to the coordination for air assets (AH-1Z) to support the QRF. It also includes the continuing coordination for optimal sortie rates to support the battle evolution.

f. MCT 6 Protect the Force

1. MCT 6.1.1.5.3 Conduct Patrolling

Patrolling consists of movement about and enemy area which facilitates an understanding of the threat condition. This is implemented concurrently with the initial convoy screening operation that initiates the combat scenario.

2. Physical Architecture

Once functionality was fully defined a physical architecture was established. Physical architecture is defined by Buede as follows.

> Physical Architecture: resources for every function identified in the functional architecture. The generic physical architecture is a description of the partitioned elements of the physical architecture without any specification to the performance characteristics of the psychical resources that comprise each element (e.g., central processing unit). *(Buede 2009)*

System form was constituted in accordance with Chapter II.D.4 (Phase III Vignette 3 Detailed Mission Development) on the basis of a scalable 1st Company definition consistent with USMC SPMAGTF architecture. The team used the 1st Company construct to specify manpower and equipment allocations for each of the three scale levels (3-Platoons, 4-Platoons, and 5-Platoons). The sections that follow describe the platoon breakdown and the detailed equipment capability descriptions of Vignette 3 including the allocation to the Spiral One Model specification. Detailed equipment specifications are tabulated in Appendix C on page 251.

a. 1st Company Composition and Allocation

Table 5 summarizes the Barra (Vignette 3) GCE composition for each of the platoon configurations. This allocation supports the map depicted in Figure 16 (GCE Barra Hybrid USMC Planning) and represents the GCE for the Vignette. The actual Spiral One Segment GCE specification for each scale consists of the QRF element and the HMMVW convoy (circled in red). These elements support Figure 18.

Table 5. Barra Vignette 31st Company GCE Composition

3 Platoons

Unit	Marines / Unit	Locations	Total Marines
Fire Team (Reinforced)	5	6	30
Rifle Squad	8	3	24
81mm Mortar Squad	3	3	9
Observation Post	4	2	8
Convoy (3 HMMWVs)	5	3	15
Capt/Corpsman	3	1	3
		Total	89

QRF

Unit	Marines / Unit	Qty	Total Marines
Fire Team (Reinforced)	5	2	10
Rifle Squad	8	3	24
81mm Mortar Squad	3	0	0
		Total	34

4 Platoons

Unit	Marines / Unit	Locations	Total Marines
Fire Team (Reinforced)	5	8	40
Rifle Squad	8	4	32
81mm Mortar Squad	3	4	12
Observation Post	4	3	12
Convoy (3 HMMWVs)	5	3	15
Capt/Corpsman	3	1	3
		Total	114

QRF

Unit	Marines / Unit	Qty	Total Marines
Fire Team (Reinforced)	5	3	15
Rifle Squad	8	4	32
81mm Mortar Squad	3	1	3
		Total	50

5 Platoons

Unit	Marines / Unit	Locations	Total Marines
Fire Team (Reinforced)	5	8	40
Rifle Squad	8	4	32
81mm Mortar Squad	3	5	15
Observation Post	4	4	16
Convoy (4 HMMWVs)	5	4	20
Capt/Corpsman	3	1	3
		Total	126

QRF

Unit	Marines / Unit	Qty	Total Marines
Fire Team (Reinforced)	5	5	25
Rifle Squad	8	6	48
81mm Mortar Squad	3	2	6
		Total	79

Table 6 summarizes the Barra (Vignette 3) ACE composition for each of the platoon configurations necessary to support QRF insertion, CAS, and Air Logistics operations for the Spiral One mission.

Table 6. Barra Vignette 3 1st Company ACE Composition

3 platoons	QRF insertion	CAS	AirLOG	Total
CH-53K	1	0	0	1
MV-22	0	0	1	1
AH-1Z	0	1	0	1
4 platoons	QRF insertion	CAS	AirLOG	Total
CH-53K	1	0	0	1
MV-22	1	0	1	2
AH-1Z	0	1	0	1
5 platoons	QRF insertion	CAS	AirLOG	Total
CH-53K	2	0	0	2
MV-22	1	0	1	2
AH-1Z	0	1	0	1

b. 1st Company Aircraft Specifications

1. CH-53K King Stallion

Platform: The team selected the CH-53K because it is a large heavy lift helicopter used for troop and equipment transportation. The CH-53K aircraft uses 2661.14 liters of fuel per hour (tool: MPEM) with a fuel capacity of 4697.696 liters (Find The Best 2014) and has an operational range of 852 km (Sikorsky 2014). The maximum speed of the vehicle is 315 km/h (Find The Best 2014). The CH-53K can carry up to 50 troops (Rivera 2014) and one HMMWV, or up to 35,000 lbs. (Tarantola 2014). The vehicle has 5 mm thick armor.

Weapons: The CH-53K has three .50 caliber machine guns each with 200 rounds of ammunition, and can fire at a rate of 0.7 shots per second (United States Marine Corps 2014). The rounds from each .50 caliber machine gun can penetrate armor of up to 21 mm thick (Cooke 2004). At short ranges of 1.6 m the weapon has a 100% chance of hitting its target; at 914.5 m it has an 85% chance of a hit; at 1.829 km it has a 75% chance of hitting its target (United States Marine Corps 2014).

Communications and Sensors: The CH-53K comes equipped with the AN/AAQ-29A is a forward looking infrared imaging system used for navigation, surveillance and target acquisition. The system allows for low-level navigation and high altitude long-range targeting (DefenseTalk 2005). The communications suite supports UHF, VHF, wideband, and SATCOM, and secure data links.

Countermeasures: The countermeasures onboard the CH-53K includes an electronic warfare management system (AN/APR-39B (V2)), infrared countermeasure system (AN/AAQ-24(V), missile warning system and a countermeasure dispenser system (AN/ALE-47). The APR-39B interacts with all onboard sensors to detect a threat, and warns the crew allowing for appropriate countermeasure to be taken (Northrop Gumman Corporation 2014). The AAQ-24V works with the APR-39B to combat infrared missiles through modern jamming technologies (Northrop Grumman Corporation 2014). The ALE-47 can be activated by the APR-39B system or manually by the crewman and will fire off chaff or flares (Symetrics Industries 2014).

2. MV-22 Osprey

Platform: The team selected the MV-22 tilt rotor aircraft as an alternative vehicle used for troop and equipment transportation. The MV-22 uses fuel at a rate of 4,672.8 liters per hour (tool: MPEM) with a fuel capacity of 6,513 liters. The operational range is 722 km (Boeing 2014) with a maximum speed of 518 km/h. The MV-22 can carry 24 troops (NAVAIR 2014) and one HMMWV or 15,000 lbs. of equipment (Boeing 2014). The vehicle has an armor thickness of five mm.

Weapons: The MV-22 is equipped with two weapons including a 7.62 GAU-17 mini gun and a .50 caliber machine gun. The 7.62 GAU-17 is a primary weapon with 3000 rounds of ammunition and can fire at a rate of 66.67 rounds per second. Each round has the ability to penetrate armor of up to 6 mm in thickness. At short ranges of 15 m the weapon has a 100% chance of hitting its target; at 546.5 m it has an 85% chance of a hit; at 1.093 km it has a 75% chance of hitting its target (Military.com 2014). The .50 caliber machine gun is a primary weapon with 200 rounds of ammunition and can fire at a rate of 0.7 rounds per second (United States Marine Corps 2014). Each round has the ability to penetrate armor of up to 21 mm thickness (Cooke 2004). At short ranges of 1.6 m the weapon has a 100% chance of hitting its target; at 914.5 m it has an 85% chance of a hit; at 1.829 km it has a 75% chance of hitting its target (United States Marine Corps 2014).

Communications and Sensors: The MV-22 uses the Remote Guardian System for target acquisition and firing capabilities. Based on an IR/CCD sensor the Remote Guardian System allows for 45 degrees/sec line of sight threat tracking. The communications suite supports UHF, VHF, wideband, and SATCOM, and secure data links (BAE Systems 2014).

Countermeasures: The countermeasures on the MV-22 include an AN/AAR-47 missile warning system, radar, infrared threat warning system along with an AN/ALE -47 chaff and flare dispenser system. The AN/AAR-47 can detect when a missile has been fired at the aircraft or a laser is being pointed and notifies the pilot as well as interfacing with the ALE – 47 (ATK Integrated Systems 2000). The ALE-47 automatically dispenses countermeasures (Symetrics Industries 2014).

3. AH-1Z Viper

Platform: The team selected the AH-1Z as the attack helicopter used for strategic strikes. The AH-1Z uses 908.5 liters of fuel per hour (tool: MPEM) and has a fuel capacity of 1,561 liters (Bell Helicopter 2004). The aircraft has a range of 685 km (Abbasi 2014) and can reach speeds up to 274 km/h (Kable 2014). The armor thickness of the AH-1Z is 5 mm thick.

Weapons: The AH-1Z is equipped with four different weapons: M197 20 mm cannon, HYDRA 70 mm rockets, AGM-114 Hellfire guided missiles, and AIM-9 Sidewinder missiles. The M197 is a 20 mm cannon with 750 rounds of ammunition and a rate of fire of 66.67 rounds per second (Aircav 2008). Each round is capable of piercing armor of up to 6.3 mm thick. The maximum range of the 20 mm cannon is two km with a 75% chance of hit (Aircav 2008). The AH-1Z comes equipped with 76 HYDRA 70 rockets (Worldwide-Military.com 2014). The rockets can penetrate armor of up to 9.71 mm thick and has a shot radius of 50 m. The HYDRA 70 rockets have a maximum range of 10.5 km at which distance it has a 75% chance of hitting its target (FAS.org 2000). The aircraft is equipped with 16 (Kable 2014) AGM-114 Hellfire missiles which can be fired at a rate of 0.5 per second (Lange 1998). The Hellfire missiles can penetrate armor of up to 120 mm thick. At a distance of 8.996 km the Hellfire missile has a 75% probability of hitting its target (Boeing 2014).

Communications and Sensors: The AN/AAQ-30 is a multi-sensor fire control system that mounts onto the nose of the AH-1Z. The system provides a large aperture mid-wave forward looking infrared sensor, color TV and laser designation/rangefinder. This allows for the ability to identify and laser-designate multiple targets at maximum weapon range (Lockheed Martin 2014). The communications suite supports UHF, VHF, wideband, and SATCOM, and secure data links (NAVAIR 2012).

Countermeasures: The countermeasures used on the AH-1Z are the AN/APR-39A Radar Warning Receiver, AN/AAR-47 Missile Warning System, AN/AVR-2A Laser Warning System and the AN/ALE-47 Airborne Countermeasures Dispenser System. The APR-39A interacts with the crewman and the other systems to detect incoming threat and warn the crew of the nature of the threat (FAS.org 2000). The AAR-47 works with the APR-39A to detect threats and provide accurate and helpful audio and visual warnings to the crewman (ATK Integrated Systems 2000). The AVR-2A is used to detect when the aircraft is being illuminated by lasers and provides warning (FAS.org 2000). The ALE-47 works with the other systems and the crewman to fire appropriate flare/chaff countermeasures when necessary (Symetrics Industries 2014).

c. 1st Company Vehicle Specifications

4. HMMWV – M1165A1B3

Platform: The HMMWV – M1165A1B3 is the armored vehicle that will be utilized for troop transportation. It consumes 22 liters of fuel per hour (tool: MPEM) and is equipped with a tank that can hold 95 liters of fuel (AM General 2010). The range of the HMMWV is 563 km (FAS.org 2000) and its top speed is 112.654 km/h. The

HMMWV is capable of carrying five equipped troops or a payload of up to 2313.32 lbs. (AM General 2010). The vehicle has 50 mm thick armor.

Weapons: Each HMMWV will have an option of having one weapon attached to the vehicle for use in fire fights. The weapon options are an M2 .50 caliber machine gun, an M240 machine gun and a M249 machine gun. The M2 .50 caliber machine gun is a primary weapon with 200 rounds of ammunition and fires at a rate of 0.7 rounds per second (United States Marine Corps 2014). Each round can penetrate armor of up to 21 mm thick (Cooke 2004). At short ranges of 1.6 m the weapon has a 100% chance of hitting its target; at 914.5 m it has an 85% chance of a hit; at 1.829 km it has a 75% chance of hitting its target (United States Marine Corps 2014). The M240 machine gun has 200 rounds of ammunition and fires at a rate of 0.6 shots per second. Each round can penetrate armor of up to 8 mm thick. At short ranges of 1.6 m the weapon has a 100% chance of hitting its target; at 900 m it has an 85% chance of a hit; at 1.8 km it has a 75% chance of hitting its target (United States Marine Corps 2014).The M249 machine gun has 200 rounds and fires at a rate of 1.4 rounds per second. Each round can penetrate armor 6 mm thick. At short ranges of 0.9 m the weapon has a 100% chance of hitting its target; at 500 m it has an 85% chance of a hit; at 1.0 km it has a 75% chance of hitting its target (United States Marine Corps 2014)

Communications and Sensors: Each HMMWV is equipped with the Harris AN/VRC-110 which allows the PRC-152 to be mounted in the HMMWV for on road communication and recharging. The VRC-110 has a separate VHF and UHF antenna port that allows for 50 watts VHF output power in the 30 – 90 MHz band, UHF antenna port allows for 20 watts at 90 – 512 MHz and 50 watts of SATCOM output. The VRC-110 / PRC-152 combination is fitted to each of the HMMWV vehicles and requires a power input of 20 – 32 VDC and 25 A for the single channel model (Harris Corporation 2010).

Countermeasures: No special countermeasures included.

5. HMMWV – M997A2

Platform: The HMMWV – M997A2 is an ambulance, light armored vehicle capable of transporting and providing limited health serviced to up to four injured Marines (FAS.org 2000). It consumes 16.3 liters of fuel per hour (Tool: MPEM) and is equipped with a tank that can hold 95 liters of fuel. The range of the HMMWV is 563 km (FAS.org 2000) and its top speed is 112.654 km/h (AM General 2014).

Weapons: No special weapons included.

Communications and Sensors: Harris AN/VRC-110 / PRC-152 configuration.

Countermeasures: No special countermeasures included.

d. 1st Company Dismount Weapons Specifications

1. M16A4 Service Rifle

The M16A4 was selected as a primary weapon carried by Marine troops. The M16A4 has 60 rounds that each Marine will carry and can fire at a rate of 0.2 rounds per second. The weapon can penetrate armor up to 6 mm in thickness. At a short range of 0.9 m it has a 100% chance of hitting its target; at 275 m it has 85% chance of a hit; at 550 m it has a 75% chance of hitting its target (United States Marine Corps 2014).

2. M249 SAW Light Machine Gun

The M249 SAW was selected as a primary weapon carried by Marine fire teams. The M249 comes equipped with 200 rounds of ammunition and can fire at a rate of 1.4 rounds per second. The bullets can penetrate armor up to 6 mm in thickness. At a short range of 0.9 m it has a 100% chance of hitting its target; at 500 m it has an 85% chance of a hit; at one km it has a 75% chance of hitting its target (United States Marine Corps 2014).

3. M9 Beretta Service Pistol

The M9 was selected as a secondary weapon carried by Marine troops. Assumptions regarding the M9 rounds and fire rate include the following. The M9 comes with 30 rounds of ammunition and can fire at a rate of 0.17 rounds per second. A bullet from the M9 can penetrate armor of up to 3 mm in thickness. At short ranges of 0.3 m the weapon has a 100% chance of hitting its target; at 25 m it has an 85% chance of a hit; at 50 m it has a 75% chance of hitting its target (MilitaryFactory.com 2014).

4. M252 Light Weight Mortar with M821HE Mortar Rounds

The M252/M821HE was selected as the light weight mortar set used by Marine mortar squads and is configured as a primary weapon. Each mortar set comes with 10 mortar rounds and can be fired at a rate of 0.3 rounds per second (FAS.org 1999). A mortar round can penetrate armor of up to 60 mm in thickness and has a shot radius of 45 m (What-When-How 2014). At a short range of 80 m the mortar has a 100% chance of hitting its target; at a range of 2.85 km it has an 85% chance of a hit; at a range of 5.7 km it has a 75% chance of hitting its target (FAS.org 1999).

5. M240B Infantry Machine Gun

The M240B was selected as the heavy, high rate primary machine gun carried by Marines troops. The M240B comes with 200 rounds of ammunition and can fire at a rate of 0.6 rounds per second. A bullet from the M240B can penetrate armor of up to 8 mm in thickness. At short ranges of 1.6 m the weapon has a 100% chance of hitting its target; at 900 m it has an 85% chance of a hit; at 1.8 km it has a 75% chance of hitting its target (United States Marine Corps 2014).

e. 1st Company Dismount IMTV Specifications

1. Improved Modular Tactical Vests

Improved Modular Tactical Vests (IMTVs) were allocated to each Marine. An IMTV assumption of 7 mm was specified.

f. 1st Company Dismount Communications and Sensors Specifications

1. Communications

For the purpose of dismount communication each 1st Company Platoon was assigned a Marine which was equipped with an AN/PRC-152 Harris radio. The AN/PRC-152 is a portable radio with Joint Tactical Radio System (JTRS) compliant Software

Communication Architecture (SCA). The radio is a hand held unit with a rechargeable battery and external antenna for extended range. The radio is equipped for communication using FM, AM, PSK, CPM and FSK. The rechargeable lithium Ion battery (NSN: 6140–01-548-7566) can power radio up to 8 hours on one charge. The external antenna (RF-3161-AT001) can be attached to the soldiers back and extend the range of the radio to similar range performance of a 3–5 kg man-pack radio system (Harris Corporation 2010).

2. Vision

The AN/PVS-14 (M914A) third generation night vision monocular was selected for dismount Marine use to enhance target acquisition and routine patrols all under low-light situations. The PVS-14 is hands free and can be connected to standard issue head gear, weapons or used in the hand. Some particular characteristics of interest of the PVS-14 include a 40.0 degree field of view, powered by one AA battery for approximately 40 hours and weighs 290 g (ASU, Inc. 2014).

3. Enemy Equipment Specifications

The following data constitutes all the gear provided to the enemy referenced in Chapter II.D.4.n.

a. Enemy Vehicle Specifications

1. Land Rover Defender

Platform: The team selected the Land Rover Defender for enemy forces to support enemy compound patrol. The vehicle uses fuel at a rate of 18.9 liters per hour (tool: MPEM) with a capacity of 75 liters. The range of the vehicle is 570 km with a max speed of 144 km/h. The armor thickness is five mm. The Land Rover Defender can transport five troops or a payload of 1,300 lbs. (Automobile-catalog.com 2014).

Weapons: The Land Rover Defender is capable of holding one of two weapons; SPG-9 or PKM. Both of the weapons characteristics are defined in the dismount weapons section since they can be emplaced in the vehicles or carried by dismounts.

Communications and Sensors: The team selected a legacy military radio (PRC-113) for enemy use on the basis that a group of hostiles are more likely to have access and funding to acquired older technology. The PRC-113 was deployed both on the Land Rover vehicles and the enemy dismount troops. The PRC-113 is portable man-pack radio that weighs 16.7 lbs. The radio works on VHF 116 – 150 MHz and UHF 225 – 400 MHz with up to 10 watts of output power allowing ranges from 5 – 15 miles (Olive-Drab 2011). The PRC-113 is powered with two BA-5590 lithium batteries supplying 15 V and up to 7.5 Ah each (SupplyNet Tactical Engineering Division 2014).

Countermeasures: None.

b. Enemy Dismount Weapons Specifications

1. MP-444 Bagira Self Loading Pistol

The team selected the MP-444 as a secondary weapon to be used by the enemy forces. The weapon comes with 15 rounds of ammunition (Sof 2012) and can fire at a rate of 0.5 rounds per second. The bullet from an MP-444 can penetrate armor up to 3 mm in thickness At a short range of 0.3 m it has a 85% chance of hitting its target; at 25 m it has a 75% chance of a hit; at 50 m it has a 50% chance of hitting its target (EnemyForces.net 2012).

2. AKS-74U Short Assault Rifle

The team selected the AKS -74U as a primary weapon of the enemy forces. The AKS-74U comes with 45 rounds of ammunition and can shoot at a rate of 1.67 rounds per second. The bullet is capable of penetrating armor of up to 6 mm thick. At a short range of 0.9 m the mortar has an 85% chance of hitting its target; at a range of 200 m it has a 75% chance of a hit; at a range of 400 m it has a 50% chance of hitting its target (EnemyForces.net 2012).

3. PKM 7.62 mm General Purpose Machine Gun

The team selected the PKM as a primary weapon of the enemy forces. The PKM comes with 250 rounds of ammunition and can shoot at a rate of 4.17 shots per second.

The bullet from a PKM can penetrate armor of up to 8 mm in thickness. At a short range of 1.2 m the mortar has an 85% chance of hitting its target; at a range of 500 m it has a 75% chance of a hit; at a range of 1.0 km it has a 50% chance of hitting its target (TRADOC DCSINT 1999).

4. SPG-9 73 mm Tripod Gun

The team selected the SPG-9 as a primary weapon of the enemy forces. The SPG-9 comes with one round of ammunition and can shoot at a rate of 0.17 rounds per second. A round from the SPG-9 can penetrate armor of up to 400 mm in thickness and has a shot radius of 10 m. At a short range of 100 m the mortar has an 85% chance of hitting its target; at a range of 650 m it has a 75% chance of a hit; at a range of 1.3 km it has a 50% chance of hitting its target (TRADOC DCSINT 1999).

c. Enemy Body Armor Specifications

1. Soft Body Armor

The team selected soft body armor for the enemy dismounts. A soft body armor assumption of 5 mm was specified.

d. Enemy Dismount Communications and Sensors Specifications

1. Communications

The team selected the PRC-113 man-pack radios for dismount troops. Detailed specifications are provided under the enemy vehicle communications section.

2. Vision: No special equipment.

4. 1st Company Function to Form Mapping

Table 7 mapped the 1st Company modeled segment specification functions to the physical form of the system demonstrating coverage for all required elements across the six war fighting functions and the decomposed 14 Marine Corps tasks selected for the mission. Equipment was broken out as aircraft, land vehicles, communication gear, sensors, weapons issued to dismounted Marines, and mortar gear. Aircraft countermeasures were not included in the functionality to be modeled due to the expected complexity and resolution requirements which would be added. Function to form mapping represents the allocation of architecture as describe by Buede (2009) in the following quote.

> Allocated Architecture: complete description of the system design, including the functional architecture allocated to the physical architecture.

Table 7. Modeled Segment Specification Function to Form Mapping

		MV-22 Osprey (weapons: 7.62 GAU-17, .50 Cal)	CH-53K (Weapons: 3x .50 Cal)	AH-1Z (weapons: M197, Hydra-70-mm, AGM-114, or AIM-9)	HMMWV (weapons: M2.5, M240, or M249)	COMS Gear (A/C, Vehicle & dismount Radios)	Sensors (A/C targeting systems, night vision & gun sites)	Dismount weapons (M164A, M249 SAW, M9 Beretta, M240B)	Mortars (M252 w / M821HE rounds)
MCT 1.3.4.1.1	Maneuver	QRF extraction	QRF extraction						
MCT 1.6.5.11		QRF insertion	QRF insertion						
MCT 1.6.11.3					Convoy Screen				
MCT 2.1.1.5	Intelligence					Targeting SA	Targeting SA		
MCT 2.1.1.6						BDA	BDA		
MCT 3.2.3.1.1	Fires			CAS					
MCT 3.2.4.1					Direct Fires			Direct Fires	
MCT 3.2.4.2									Indirect Fires
MCT 4.3.8	Logistics	Air LOG							
MCT 4.5.5			MEDEVAC						
MCT 5.3.1.2	Command & Control					Tactical C2			
MCT 5.3.4.4						Ground fires C2			
MCT 5.3.4.5						CAS C2			
MCT 6.1.1.5.3	Force Protection				Convoy Patrol				

C. MEASURES OF EFFECTIVENESS

1. Source and relation to functionality

The MCTL was examined for measures which were used to support the team's AoA. Specifically, metrics for each task identified in Chapter II.E.1functional hierarchy were required to allow data collection and construction of overall MOEs that supported the study of trades between operational effectiveness and operational energy.

The team began with the assumption that the measures listed in the MCTL were meaningful MOEs for those individual tasks based on the doctrine promulgated in the subject document. The team also assumed that overall measures of effectiveness could be constructed from these individual measures for each of the six warfighting functions.

2. Screening method

The method used to screen measures from the task list consisted of the following process. First, measures which were not in scope on the basis of the mission concept were eliminated. The remaining measures were examined. The team retained measures which were anticipated to be supportable by the executable model. The team retained measures that are not expected to be changing values in the model, but which should be considered to have a bearing on an overall measure of effectiveness because they are part of the assumptions that frame the war fighting functional effectiveness. The team retained measures which it did not expect the executable model to support, but which were anticipated to be creatable from other modeling methods. The remaining measures were eliminated.

The engineering team recognized that obtaining data on the resulting measures would require successful implementation of both executable modeling and supplemental modeling techniques. Since this was an unknown at the time of the measure development, the measures selected and shown in Table 8 were considered to represent the candidate measures to support the tradespace analysis. These measures were subject to further review including additional construction and elaboration in the modeling phase of the project.

3. Measures of Effectiveness vs. Energy Metrics

The engineering team specified measures of effectiveness and provided guidance that energy should be considered the independent variable in subsequent analyses. On this basis the modeling team was given latitude to develop metrics necessary for the collection of related energy driver data to support the trade study.

4. MOE Thresholds and Successful Mission Definition

The MOE threshold values shown in Table 8 represent the engineering team's determination of the correct values for the Barra mission execution based on doctrinal guidance or engineering judgment. The team believed that the successful execution of the Barra CONOP suggested that associated MOE threshold values had to be met. A subjective criterion was developed that balanced the effectiveness threshold requirements between each of the war fighting dimensions. Success was predicated on the determination that the operation met all critical threshold MOEs and met at least 50% of the remaining non-critical MOEs. Table 8 details the criticality for each measure.

Table 8. Modeled Segment Specification Tailored Measures of Effectiveness (after United States Marine Corps 2014)

#	Type	Description of Measure	Threshold / Objective	Critical (y/n)
MCT 1.3.4.1.1 Conduct Airborne Rapid Insertion/Extraction				
M8	Time	To provide extraction operation.	30 min / 25 min	N
MCT 1.6.5.11 Conduct Quick Reaction Force Operations				
M1	Percent	Force required for Quick Reaction Force operations.	100% / 75%	N
M2	Time	Quick Reaction Force reaction time.	15 min / 15 min	Y
MCT 1.6.11.3 Conduct Screen Operations				
M3	Percent	Of enemy troops detected before they could come into contact with friendly flanks or rear areas.	90% / 100%	N
M4	Percent	Of enemy troops detected which were engaged by fire support or maneuver assets before they could come into contact with friendly flanks or rear areas.	95% / 100%	N

#	Type	Description of Measure	Threshold / Objective	Critical (y/n)
MCT 2.1.1.5 Support Targeting				
M1	Y/N	Targets assigned relative value.	N / Y	N
M3	Percent	Of targets available for striking.	75% / 100%	N
M4	Percent	Of prioritized targets collected upon.	90% / 100%	N
M9	Y/N	Maintain display of current enemy situation with target locations and priorities.	N / Y	N
M14	Incidents	Of Blue-on-Blue engagements.	3 / 0	Y
MCT 2.1.1.6 Support Combat Assessment				
M1	Percent	Of struck targets assigned collection assets.	90% / 100%	N
M5	Y/N	Intelligence capable of being acquired to support Assessment (e.g., COMCAM, Imagery, SIGINT, HUMINT, CA, etc.).	N / Y	N
MCT 3.2.3.1.1 Conduct Close Air Support (CAS)				
M4	Number	Of sorties daily sustained during contingency/combat operations.	1 / 2	N
M7	Percent	Of enemy targets engaged.	10% / 30%	N
M8	Percent	Of targets attacked with desired effects.	95% / 100%	N
M10	Percent	Of friendly forces covered by CAS.	95% / 100%	N
M12	Number/Percent	Incidents of fratricide.	5% / 0%	N
M17	Percent	Of weapons effects on target (percent of desired effects achieved).	95% / 100%	N
MCT 3.2.4.1 Conduct Direct Fires				
M1	Percent	Of targets attacked with desired effects.	16% / 46%	Y
M4	Number	Incidents of fratricide while attacking targets in support of operational maneuver.	1 / 0	Y
M5	Y/N	Take the enemy under fire using lethal and nonlethal gunfire delivered on target.	N / Y	Y

#	Type	Description of Measure	Threshold / Objective	Critical (y/n)
M6	Number	Of missions completed.	1 / 2	Y
MCT 3.2.4.2 Conduct Indirect Fires				
M1	Percent	Of targets attacked with desired effects.	90% / 100%	Y
M4	Number	Incidents of fratricide while attacking targets in support of operational maneuver.	1 / 0	Y
M6	Y/N	Apply indirect fire, ground-based weapon systems.	N / Y	N
MCT 4.3.8 Conduct Air Logistic Support				
M5	Number	Of sorties daily sustained during contingency/combat operations.	0 / 1	N
M8	Percent	Of required support material distributed at the time and place required.	90% / 100%	N
MCT 4.5.5 Conduct Casualty Evacuation				
M6	Hours	From wound or injury until person is in surgery or other appropriate care.	2 / 1	Y
M8	Percent	Of casualty death. (injured died in route)	5% / 0%	Y
MCT 5.3.1.2 Exercise Tactical Command and Control				
M1	Time	For units to respond to tasking.	5 min / 5 min	N
M2	Time	Delay in response to orders.	5 min / 5 min	N
M3	Percent	Of units responding appropriately to orders.	95% / 100%	N
MCT 5.3.4.4 Coordinate Ground Surface Fires				
M1	Number	Of targets successfully engaged.	90% / 100%	Y
M4	Number	Of fires on friendly/neutral forces.	2% / 0%	Y
MCT 5.3.4.5 Coordinate Close Air Support (CAS)				
M3	Percent	Of friendly aircraft lost per sortie.	0% / 0%	Y
M5	Number	Of fires on friendly/neutral forces.	2% / 0%	Y

#	Type	Description of Measure	Threshold / Objective	Critical (y/n)
M6	Percent	Of enemy units detected, were engaged.	10% / 20%	N
M7	Percent	Of enemy units engaged, were downed.	90% / 100%	N
M8	Minutes	Of on-station time of CAS support.	60 min / 30 min	Y
MCT 6.1.1.5.3 Conduct Patrolling				
M1	Incidents	Of friendly operations degraded due to enemy observation, detection, interference, espionage, terrorism and/or sabotage.	1 / 0	N
M2	Incidents	By enemy troops, or partisans, affecting security of force and means in the operations area.	1 / 0	N
M9	Y/N	Urban patrolling conducted.	N / Y	N

D. CHAPTER SUMMARY

The operational concept was subjected to further architecture development. In particular, the form, function, and metrics of the desired mission segment were specified. Function was decomposed from the six war fighting functions using the Marine Corps task book. Form was specified for each of the three scale levels on the basis of USMC standard SPMAGTF composition. An equipment list with detailed specifications was presented. A function to form matrix was presented to demonstrate coverage for all required functionality in support of the mission. Measures of effectiveness were specified from the Marine Corps task book through a detailed screening process which the team designed. A criterion was established for the successful execution of the Barra mission which was later used in the AoA.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. MODELING AND SIMULATION

A. INTRODUCTION

The team executed initial systems engineering process elements to inform the creation of an executable model which was eventually used to predict the system effectiveness in a defined operational context. Specifically, four key artifacts were provided from the initial engineering process to facilitate construction of the model. The functional hierarchy defined in Chapter III.B.1 established the framework for what the system does. The physical architecture defined in III.B.2 determined what the system is. The mission analysis elaborated in II.D.4.n provided the context for where and the conditions under which the system operates including the threat conditions. Finally, measures of effectiveness provided in III.B.5 established the quantitative means by which the system effectiveness would be determined. Together these artifacts form the specification for the construction of the modeled segment.

The modeling and simulation effort began with the engineering specification and the objective of representing all which it implies in an executable model that is capable of providing a prediction of the system's effectiveness. The analysis in this chapter articulates the team's journey in support of this objective and is summarized as follows. The approach and tool selection analysis defines the process and basis for tool selection and use by the team. Model input considerations provide details regarding methods for system properties collection and accounting. Model design presents foundational information regarding the techniques, assumptions, and limitations for the representation of the system function and form in the specified operational context; and provides a detailed design description for the actual model representation. The design description includes all aspects of the model design that were able to be fully implemented and debugged in the time available. In lieu of a complete implementation, the design Chapter IV.D concludes with reconciliation statements that discuss this gap and the implications to the study. Output considerations address processing requirements, meta-modeling, and statistical metrics necessary to support tradespace analysis. Design of experiments describes the overarching experimental process and experimental planning performed by the team to support experimentation and data collection. The Design of Experiments (DOE) section also presents alternative options for experiment design which the team did not pursue.

B. MODELING AND SIMULATION APPROACH AND TOOLS

1. Selection of modeling paradigm

The team examined Discrete Event Simulation (DES), Agent Based Modeling and Simulation (ABMS), and continuous modeling methods. Discrete Event Simulation is often associated with queuing systems and a low number of interactions (Law 2007). Agent based Modeling and Simulation on the other hand supports autonomy and multiple agents with many interactions. It was clear to the team that the mission concept and notional system to be modeled suggested many interactions were necessary. Additionally, the team desired to investigate the coupling of energy commitments to autonomous activity in the battle space. A third alternative considered, continuous modeling, allows representation of system dynamics through closed form mathematical means, but the team determined it would difficult to represent decision making activity represented in the mission CONOP with this method (Law 2007). For these reasons ABMS was selected for the primary modeling paradigm.

With ABMS selected for the modeling paradigm, the next step was to determine a specific tool to implement that approach. A variety of tools were available for selection and the challenge was to select a tool with a manageable learning curve for the time constraints of this capstone. This required a tool with resources, such as sample models and manuals, and relative ease of development. In Figure 23, MANA was compared with other available ABMS tools in order to establish a context of available ABMS for tool selection.

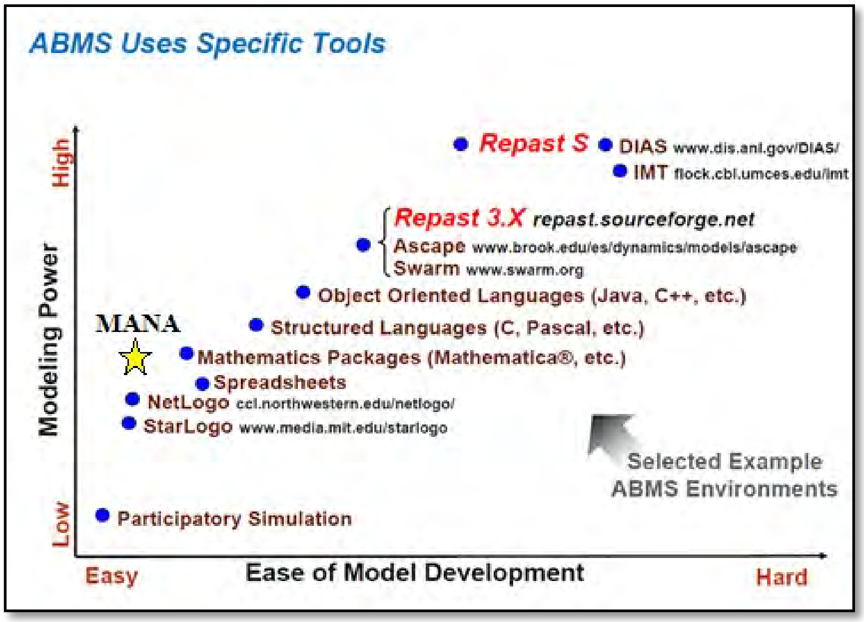


Figure 23. MANA vs. ABMS Spectrum (from Macal and North 2006)

Commercial and military ABMS tools were examined, and MANA was selected based on the criteria fulfillment as shown in Table 9. MANA is an ABMS software package developed by the Defense Technology Agency (DTA) in New Zealand. In summary, MANA provided the best fit and was available along with support from the NPS Simulation Experiments and Efficient Design (SEED) Center for Data Farming. In spite of meeting the selection criteria, the team did determine there were risks associated with the use of MANA, including learning curve time, and energy modeling fidelity. The team executed a risk mitigation strategy which included the use of on-line training modules and development of energy link analysis to corroborate the MANA fuel output. The team determined that supplemental modeling could be supported with a combination of spreadsheet software that included mathematical add-ins and statistical software.

Table 9. ABMS Selection Criteria and Fulfillment

Criteria	MANA Attribute
Tool should model agents of type used in USMC operational context	Supports military context
Tool should be readily available with existing license	Available through NPS
Tool documentation and tutorials should be readily available	Documentation and tutorials on SAKAI
Tool support should be readily available	Support through SEED center

2. Model construction process

The MANA model construction process was conceived to accommodate the specifics of producing an executable model which would supply data that allows the tradespace construction described in the Chapter III. The model construction process was seen as a simple input, design, and output sequential process. Input considerations included methods to collect agent properties and fuel data as well as methods to organize agents into squads on a map with the correct platform, weapon, and sensors capabilities. The model design process addressed the details of how the form and function of the system were represented in the context established by engineering team such that experimental data is attainable for output consideration. For the output considerations the process examined processing requirements, such as those needed for number of iterations of the model at each design point, meta-modeling, and statistical analysis. It is important to note that this process was used to construct the model not the experiment. The experiments were conducted using constructed models for each scale based design point established by SE. Additional design point considerations were examined and are presented in the DOE Chapter IV.E.

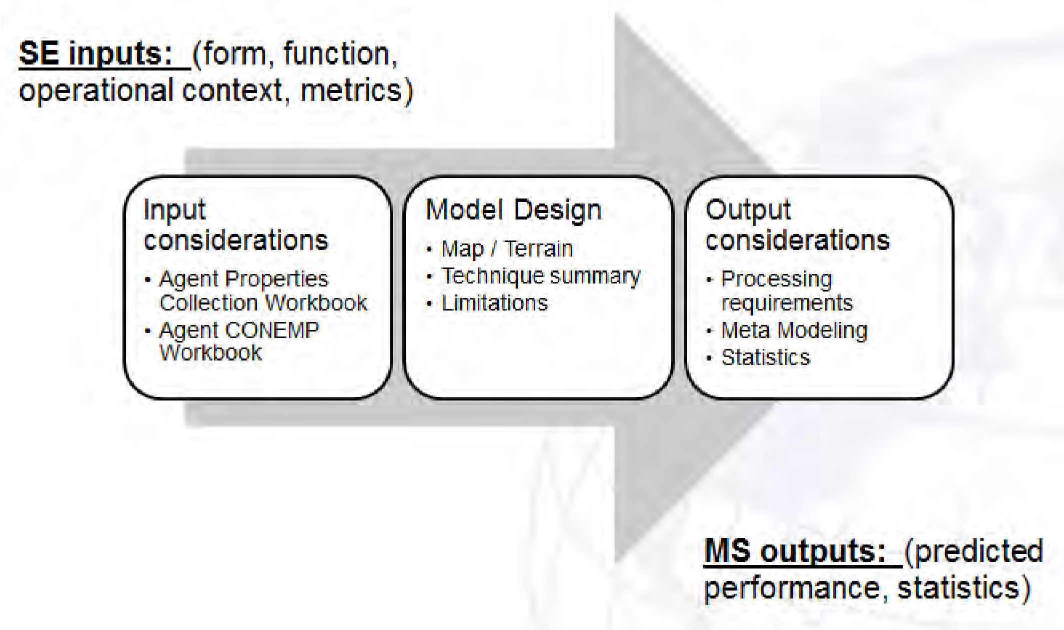


Figure 24. MANA Model Construction Process

3. Modeling Tools

Six key tools were used to implement the modeling and simulation process as shown in Table 10. Microsoft Excel proved to be a beneficial tool for collection of raw agent properties and manipulation of that data into a form that is useful for MANA. Additionally, Excel served a key role in holistic accounting for required MANA properties. Excel was also used for metrics construction, data manipulation, and supplemental energy link and tradespace analysis.

The Marine Air Ground Task Force Power and Energy Model (MPEM), which was provided by the E2O, provided the necessary energy profiles as well as fuel usage for the agents in the MANA simulation. According to the MPEM User Manual, MPEM is a powerful tool that can be used to model the energy consumption of the Marines (United States Marine Corps 2011). This tool was chosen to assist in the modeling because of the centralization of data, tool availability, and insight into agent characteristics that may not be readily available elsewhere.

As previously discussed MANA was the key executable ABMS tool used to represent the operational architecture. JMP 11 was used for statistical analysis. Easy Google Map Downloader was used for the development of a high resolution map of the Barra Area of Interest. The team used MATLAB (R) to build scripts for harvesting data files produced by MANA to support metrics requirements.

Table 10. Modeling Tool Use

Tools Used	Use
MS Excel	Collection of agent properties Manipulation of performance data suitable for MANA input Accounting tool for all MANA input requirements Supplemental energy modeling and tradespace analysis
MPEM	Source for fuel consumption data
MANA	Executable agent based model support
JMP 11	Statistical analysis
Easy Google Map Downloader	Stitch tool for high resolution map creation
MATLAB	Used to create scripts for MANA output data harvesting

C. MODEL INPUT CONSIDERATIONS

The team designed methods for gathering and accounting for input details that were used to construct the MANA models. A detailed agent properties workbook was created using Microsoft Excel to implement the MANA schema for collection and tracking of MANA properties. A second Microsoft Excel workbook was developed to track the Concept of Employment (CONEMP) for the simulation. The CONEMP defined agent names, organized them into squads, emplaced them on the Barra map, and further specified remaining attributes of the simulation.

1. Agent Properties Workbook (Spiral One)

The Agent Properties Workbook contained tabs for red and blue force MANA schema data collection, red and blue force data source references, input data assumptions, and text drop down list definitions. The Agent Properties Workbook does not replicate based on the three cases of spiral one because it defines agent properties without regard to their instantiation. The workbook tabs are further elaborated as follows.

a. MANA Schema Parameter Tracking

Parameter tracking was established for MANA weapons, sensors, and platform properties as shown in Table 11, Table 12, and Table 13. The tables allocate and define the agent capability schema *(McIntosh et al. 2007).*

The agent properties workbook does not track behavioral based agent properties such as agent propensities. Model design and specification of each of these parameter values is the subject of Chapter IV.D.5.

Table 11. MANA Weapons Properties Schema (after McIntosh et al. 2007)

Data Element	Units / Range	Definition
Weapon class	Primary/secondary	Used to match weapon lethality to target type
Weapon number	1-6	Priority list for weapon selection and ammo depletion
Weapon model	Simple/advanced	Fidelity setting for weapon modeling
Fire mode/target	Kinetic/high explosive, SA (squad or inorganic)	Kinetic applies to non-explosive, squad SA used for squad level targeting only, inorganic SA used for intra-squad targeting
Lock parameter value to default state	Yes/no	Propagates weapons parameters for each agent and weapon across all trigger states
Walls and hills block fire	Yes/no	Used to specify weapons which can shoot around or over such as mortars from weapons which cannot shoot through such as hand guns and rifles
Shots/ammo	Quantity	Total quantity of shots weapon is issued with
Enable in this state	Yes/no	Enable for weapon is available for each trigger state
Shots/sec	Quantity/second	Number of shots the weapon can fire per second
Armor penetration	Millimeters	Maximum armor thickness that the weapon can penetrate
Range/accuracy calculation data	% hit rate at three specified ranges in Meters	Used to specify target hit rate at each of three different ranges that you select.
Interpolate within sub-ranges	Yes/no	Allows linear interpolation between three range points for hit rate percentage
Fire on closest target first	Yes/no	Toggle for setting close targets as priority
Shot radius	Meters	Hit radius for kinetic energy weapons
Aperture angle	Degrees for arc and offset	Angle and offset for the fixed mount weapon on agent

Table 12. MANA Platform Properties Schema (after McIntosh et al. 2007)

Data Element	Units / Range	Definition
Armor thickness	Millimeters	Specified armor thickness of aircrafts, vehicles, or dismount agent protective gear
Fuel consumption	mL / sec	Constant fuel consumption rate
Range	Kilometers	Maximum range of platform used to calculate fuel consumption rate in worksheet if not otherwise specified in source data
Fuel tank	Liters	Fuel tank capacity
Auto re-fueler	Yes/no	Yes if this agent is capable of re-fueling other agents
Terrain affects movement	Yes/no	Yes if ground vehicle, no if aircraft
Constant speed	Kilometers/hour	A configurable speed per trigger state which is a constant level for the duration of the trigger state
Capable of carrying troops	Yes/no	Yes if this agent is used to carry troops
Capable of carrying vehicles	Yes/no	Yes if agent is used to carry vehicles
Capable of being carried	Yes/no	Yes if agent can be carried by another qualified agent
Max number of troops carried	Quantity	Maximum quantity of troops that are allowed to be carried which can be carried by the platform
Max vehicles carried	Quantity	Maximum quantity of vehicles that are allowed to be carried which can be carried by the platform
Max payload in lbs.	Lbs.	Maximum payload setting of the platform regardless of quantity

Table 13. MANA Sensor Properties Schema (after McIntosh et al. 2007)

Data Element	Units / Range	Definition
Sensor name	Text	Text name used to uniquely identify each sensor
Sensor number	1-6	Priority list for use of each sensor capability on a platform
Master enable	On/off	Master on/off switch for each sensor on each agent for all trigger states
Sensor model	Simple/advanced	Fidelity setting for sensor modeling
Sensor class	Primary/secondary	Used to identify the type of observations that are objectives for each sensor type
Enable in this state	Yes/no	Used to enable sensor for each agent at each trigger state level
Detect range	Meters	Maximum range at which the sensor can detect another agent
Classify range	Meters	Maximum range at which the sensor can determine whether another agent is friend, foe, or neutral
Lock to class range	Yes/no	Causes detect range to be equal to classify range
Aperture (arc/offset)	Degrees	Angle and offset (field of regard) for the fixed sensor on agent

b. Data Sources

Input to the agent properties workbook was obtained from the SE specification of function and form Chapter III.B, which included examination of the data sources for blue and red forces. Together this data provided performance specification data as well as payload data for determining correct allocation of weapons and sensors to platforms and troops.

c. Assumptions

The Agent Properties Workbook contains a tab to gather all assumptions related to how the MANA properties are established from known capability specifications. MANA is considered a low resolution modeling tool because the focus is on autonomous decision making rather than high resolution device modeling. For this reason, it was necessary for the team to make certain assumptions and decisions regarding how MANA would be used to represent certain characteristics. Assumptions established the representation of armor and penetration, weapon range, fuel consumption rate, platform maximum speed, payload employment, and ammo quantity. Details are provided in Chapter IV.D.5.

d. Text Option Drop down Lists

The team created a tab to allow for MANA schema correct drop down lists in the agent properties data entry worksheets. This provided for consistency and quick data entry for the agent data.

2. Agent CONEMP Workbook

The Agent CONEMP Workbook provides three tabs representing each of the three cases of spiral one scale factor. The blue and red force data, which are included in each tab, are described as follows. Maps are included which define the placement of all agents, routes, paths, and other key detail necessary to define the employment. Force composition is defined at the squad and platform level such that the allocation of gear and assignment of troops and squads to platforms is defined. Squad naming conventions are applied as well as agent numbering such that all elements of the QRF, fire teams, rifle squads, mortar squads, QRF insertion air assets, HMMWVs, Land Rover, and dismounted troops are accounted for.

3. MANA Input Workbook Update Process

The team established a discipline regarding the MANA input workbooks with the objective to find and use the best data representation of agents and their employment based on the SE specifications notwithstanding the low resolution capability of MANA. Practically, this meant the team had to follow rigor when it came to establishing and updating the workbooks. The following four-step process was use to implement this rigor. Iteration was used as needed to achieve the final executable model.

<u>Step one – Initial MANA Input Workbook Build</u>: The initial workbooks were built from SE data, assumptions, and the CONEMP. The initial workbooks provide all of the information necessary to do the initial MANA model input.

Step two – Initial MANA Model Input: MANA input data from step one was input directly into the MANA input screens. The data was replicated on each of the three models used to represent the scale factors in spiral one.

Step three – MANA Model Execution and Debug: The MANA model was execute and debugged. In this process the team found it necessary to update input parameter values and revise assumptions in order to resolve executable representation issues.

Step four – Workbook Reconciliation and Update: The final step required the team to revise the MANA input workbooks, including update of parameter values and associated assumptions.

D. MODEL DESIGN

1. MANA Model Scoping Statement

The modeling team was charged with the construction of MANA models to represent three levels of scale in order to demonstrate energy drivers specified in the Spiral One engineering specification. As the effort evolved, it became apparent that the team would not have enough time to fully implement all of the specified components. The decision was made to focus on the core elements necessary to achieve a blue – red battle engagement where the blue force was supported by the ACE inserted QRF. This would provide the minimum combination of a key energy driver (the air insertion) with the key effectiveness driver (the land battle). The following list of elements represents the features the model did not implement and represent objectives for energy link analysis described in V.C and future research efforts detailed in Chapter VI.D.

- CAS
- Air Logistics Support
- Casualty Evacuation
- Communications links and situational awareness
- Indirect Fires

In lieu of completing a debugged MANA model with of all these features present, the team developed artifacts to govern their eventual completion. Certain aspects of these artifacts may be discussed in the design narratives that follow and appear in the appendices and deliverable files.

2. Limitations and Constraints

Several MANA limitations had a bearing on the modeling progression. This section describes the fundamental issues the team faced in this regard. When possible the team constructed actual work-around methods inside of MANA. In cases where there was no possible MANA work-around method, the team attempted to resolve the issue through modeling outside of MANA. In either case the objective was to adequately represent the system form and function to allow the prediction of effectiveness and energy consumption. These methods employed are described in the design details in this chapter.

a. Map Resolution

The necessity for a high resolution map at Barra to simulate terrain prevented the team from incorporating longer ranges into the model. Although long range maps could have been implemented at low resolution, this would have precluded the high resolution Barra map use in the same model. This presented a problem for coupling energy drivers based on long distance with energy drivers based on autonomous agent behavior. There was no work around for this limitation. Rather, the limitation was a key consideration that the engineering team used to scope the modeled segment to the Barra area of operations.

b. Step Limitation

During initial model design the team discovered a step limitation. The step limitation of 100,000 maximum cycles suggested that the maximum simulation length using one-second cycles is 27.78 days. This prevented the team from modeling long steady state operations in combination with shorter engagements that require the one-second resolution. The step limitation was brought to the attention of the SEED center, and a new release without the limitation was subsequently made. Unfortunately, the release was not done in time to allow the team to incorporate long cycles into the existing model. As with the map resolution, the step limitation influenced the determination of the mission to be modeled.

c. Scripted vs. non-scripted methods

Although not necessarily a MANA limitation, the use of scripted methods in lieu of autonomous modeling results in decoupling of run-time agent based decision making from the measures of effectiveness that allow building of the tradespace. Specifically, the team mitigated this issue by partitioning the scripted versus autonomous segments of the simulation. Time constraints prevented the team from investigating a MANA strategy to incorporate autonomous command control sequences.

d. Difficulty in coding defensive agent posture

The team had great difficulty in achieving adequate defensive posture in agent behavior. This resulted in short battle engagements which made it difficult to assess energy drivers that are based on battle length. The implementation of tactics through behavioral settings is a difficult but worthy proposition for further study using MANA. Ultimately, the team achieved some degree of balance in the agent behavioral by equally dividing movement propensity between battle engagement and objective area attainment. This method is further discussed in IV.D.5.c.

e. Battle damage assessment

MANA does not provide adequate run time visibility into casualty rates to allow autonomous command and control sequences for implementation of features such as casualty evacuation. In particular, the team was interested in using casualty and injury information during the execution of a run to inform agent behavior. The desire was to use thresholds to cause triggering of states in which casualty evacuation measures would be taken, thus allowing organic modeling of a key energy driver in the battle space. The team was able to extract data regarding casualties after simulation runs complete to infer BDA data to support analysis in Chapter V.

f. *Output data limitations*

MANA does not include a robust output data manipulation facility. Specifically, the team was interested in data which was not readily provided in a single MANA output file. MANA produces a large data set of multiple files representing the entire set of runs generated in an experiment. A summary file is provided that is less than robust. In order to gain visibility of key data for metrics collection which is not in the output summary, it is necessary to manually reduce or compile the data in the large data set. The team wrote scripts using MATLAB (R) to assist in this data reduction. Details of the methods are provided in Chapter IV.F.

3. MANA Technique Basics

Seven specific modeling techniques were of significant importance for the design of the modeled segment. Appendix E on page YY contains MANA background techniques to support the design discussion that follow in this chapter. MANA background techniques discussed include Embussing, Situational Awareness and Communications, Fires Execution, Terrain Modeling, Agent Bases Behavior and Trigger states, and Squad Maps. Additional graphical artifacts of the design process are also included in Appendix E.

4. Background and Terrain Map Design

The MANA model construction required the creation of two maps to govern the highest level of spatial context in the simulation. The background map, which was constructed from a high resolution satellite photo of the Barra region, provided a visual representation for the user running the model. The terrain map, which was constructed from the satellite map, provided MANA with an estimated representation of the Barra terrain. Both of these maps, their construction, and specification are discussed in the sections that follow.

a. Background Map Construction

The background map was created using Easy Google Map Downloader and edited down to its final size and shape using a photo editor. The map downloading software allows the user to pull highly detailed map segments from Google Maps and provides a stitching process to combine them into a single seamless map. The software allows the user to provide the latitude and longitude coordinates of the desired location as well as the zoom level or detail desired for the output map. The software then pulls each individual image from the Google servers and stitches the files together to create one highly detailed map.

A distance scale was then added to the left side and bottom edge of the map to provide a perspective on the actual size of the area of interest. The final file was then exported as a Bitmap image (55.3 MB in size) for use in the MANA model. An image showing the full area of the Barra region used in the MANA model is shown in Figure 25. This background provides a visualization to enhance the appearance of the modeled area.

Figure 25. Barra Area Background Map

The map was created using a high enough resolution to provide enough detail to allow for distinction between buildings, trees, boats, streets and other urban areas of interest. This provided the ability to model the MANA agents in a real world urban setting. The resolution provided by this map is demonstrated in Figure 26. This figure shows a small section of the lower right hand corner of the map to illustrate the detail provided by the map.

Figure 26. Zoomed in Portion of the Barra Map to Show Detail

b. Terrain Map Construction

In order to create a terrain map that can be interpreted by MANA, a duplicate of the background map was made so that it could be used as a foundation. MANA allows the representation of terrain using a Bitmap image that consists of a series of different colors. These different colors are represented as an RGB or Red, Green and Blue color value. Each RGB color is then assigned a terrain type in MANA along with three properties that affect how the simulation will be affected by that particular color. The three adjustable properties (Going, Cover, and Concealment) and the terrain types for which they apply are shown in Table 14. The table reflects the final values selected by the team to represent the Barra terrain map.

Table 14. Barra Map Terrain Features with Final Values

Name	Terrain Attributes			Color		
	Going	Cover	Concealment	Red	Green	Blue
Billiard Table	1.00	0.00	0.00	0	0	0
Water	1.00	0.00	0.00	25	115	239
Road	1.00	0.00	0.00	255	255	0
Dirt/Land	1.00	0.00	0.00	189	181	82
Light Brush	0.75	0.90	0.90	08	255	08
Dense Brush	0.20	0.95	0.95	41	181	41
Wall/house	0.00	1.00	1.00	189	189	189

Table 15 represents the color system definition for each of the terrain types which are also user definable. The values selected in the system describe the terrain in terms of the attributes and therefore determine certain aspects of how agent activity progresses. For example, attributes for the terrain feature "Light Brush" indicate the speed or ease at which an agent moves through the cell (Going), the degree to which agents can be shot by direct fire weapons (Cover), and the degree to which an agent can be observed in the terrain (Concealment). Terrain types are defined in Table 15.

Table 15. MANA Terrain Type Definitions (after McIntosh et al. 2007)

Terrain Type	Definition
Billiard Table	"Colored black, plain terrain that has no special properties (McIntosh et al. 2007)."
Water	"Colored blue, used to represent body of water. Properties can be used to set sea conditions including fog (McIntosh et al. 2007)."
Road	"Terrain that represents a road or other region that is particularly easy to move along. Yellow coloring represents these areas. Entities can have personality weightings set towards Easy Going terrain. Thus, a "convoy" can be made to stay close to a road if the surrounding terrain would affect its movement speed (McIntosh et al. 2007)."
Dirt/Land	"Represents basic dirt/land with no special infrastructure for easy going movement (McIntosh et al. 2007)."
Light Brush	"Bush terrain is represented by light green coloring. Differing density provides different movement speed, cover from weapons fire and concealment multipliers (McIntosh et al. 2007)."
Dense Brush	"Extra category for brush represented by dark green coloring (McIntosh et al. 2007)."
Wall/House	"Obstacle terrain that is represented by light grey colorings. No entity may occupy an obstacle cell. Entities can see through wall cells only if 'Line of Sight' is turned off, and entities can fire kinetic energy weapons through wall cells only if the weapons are explicitly set to allow this (McIntosh et al. 2007)."

Once each of the representative RGB colors were defined the existing satellite-based background map had to be translated into an equivalent terrain map that consisted of an approximated representation of the terrain. This process was done manually using photo editing software. The duplicated copy of the background map was imported into the photo editing software and the terrain map was then created by tracing over the distinct areas of terrain with its assigned model RGB color profile. Each building, street, waterway, dirt area, and brush variation was approximated using the details provided by the satellite image map. This process produced a simplified version of the Barra map that was of the same resolution as the background map so that they could be used together effectively within the model. Each street or house on the background map would correspond to a terrain map equivalent on the terrain map. The completed version of the terrain map is shown in Figure 27.

Figure 27. Barra Area Terrain Map

The detailed translation from satellite map to terrain map is shown in Figure 28 by zooming up on approximately the same lower right hand region of the map as depicted earlier in Figure 26.

Figure 28. Zoomed In Portion of the Barra Terrain Map to Show Detail

The detail provided by this high resolution terrain map allowed for additional definition in the model by providing obstructed movement, cover and concealment during the simulation. This terrain map helped to provide an approximated terrain experience for the MANA agents in this urban setting. The final terrain map resolution was represented as a 6770 wide by 4288 high cell grid using 16 bit color, distributed over a 3000 meter by 1900 meter background map. The resolution provided a cell resolution of 5.093 m^2.

c. Map design considerations

1. Terrain map attribute adjustment

Model execution and debugging provided an opportunity to modify terrain attributes. The team discovered that these changes were necessary to provide a realistic representation of an agent's going, cover, and concealment provided by the terrain in the greater Barra area. For example, examination of the simulation run revealed that agents were being identified and subsequently shot and killed from what amounts to be several city blocks away. It was then determined that the cover, and concealment factors for some of the light and dense brush were too low. By increasing the cover and concealment attributes for these two terrain types the team was able to reduce the occurrence of agents being killed via cross-town attack.

2. Background and terrain map utilization

Once the final terrain map settings were specified (Table 14), the terrain map was locked down and used solely to describe the terrain to MANA. The background map served as a building block for CONEMP implementation, including the placement of agents, and the route creations that governed the agents' movements. As an added visual benefit to observing the model run, the team also built a combined layered map which shows the MANA terrain colors on top of the background map.

3. Map resolution

Initial map considerations included the creation of a map that would encompass an entire mission area between Dakar and Barra including seaward littoral regions out to 30 miles. This broad map requirement was ultimately removed by the engineering team based upon design considerations discovered while attempting to build a large map. Ultimately the team discovered that the required map file size and resulting map cell resolution were not compatible with the executable model the team wished to build. The map file size of 7 GB resulted in unacceptable MANA run time execution. The broad map area desired would result in a cell resolution which was considered to be too low to describe the detailed terrain the team desired to model.

5. Agent Properties

a. Scope

This section explains how the team elaborated the agent and squad property data and provides the assumptions, techniques, and specification of the actual values. Two files govern the input to the design section including the agent properties workbook and the agent CONEMP workbook as described in Chapter IV.C. This following narrative defines parent-child relationships, discusses agent property representation techniques and assumptions, and provides the detailed agent and squad specification. Blue forces refer to CJTF elements, and red forces refer to the enemy elements (FSM).

b. Squad Representation and Parent-Child Relationships

A squad was specified as either single or multiple agents depending on the hierarchical relationships necessary to represent the CONEMP. Additionally, squads and/or agents were specified to be part of a parent-child relationship on the basis of whether they needed to be embussed and/or debussed (see Appendix E for details) as part of the simulation sequence. The team developed MANA squad and/or parent-child structures as needed for the blue force HMMWV and QRF, and the red force Land Rover and ground forces. These squad and agents specifications are detailed in Chapter IV.D.5.d. MANA squad and parent-child constraints are discussed next and followed by the discussion of the base methods used for the allocation to the associated hierarchy.

The following MANA definitions and constraints bounded the teams' implementation of the squads and parent-child structures. The team considered these constraints a sensible way to maintain coherence in the simulation, although they did increase the complexity of the representation. These fundamental constraints were derived from MANA experimentation and reference to MANA manual understanding (McIntosh et al. 2007).

- A squad is the minimum logical building block that contains agent(s).
- Every agent must be associated with some squad.
- Every agent can only be associated with one squad.
- Each squad can have only one weapons configuration, which is defined by the set of primary and secondary weapons in the configuration.
- Squads are not required to be associated with a parent or a child.
- A parent is a type of squad that can have associations with multiple child squads.
- A child squad is a type of squad that can have a single association with one parent squad.
- The parent-child relationship is used to facilitate embussing and debussing.
- Squads that are not a child squad cannot be embussed or debussed.

1. Blue Force Vehicle Squad Representation Method

The following method was used by the team to specify and represent the squad properties for HMMWV vehicles in the blue force convoy. This method was repeated for each blue force vehicle in the model.

The naming conventions for the squad names associated with a vehicle parent and a child squad relationship are shown in Figure 29. The naming convention was used for replication purposes to elaborate all HMMWV vehicles based on this example. The parent convention incorporates a vehicle type, number, and inherent agent number. The inherent agent represents the agent/operator of the vehicle that stays with the vehicle. The child naming convention creates a unique association by incorporating the child squad weapon type, parent vehicle type, and parent vehicle number. This ensures the child squad is appropriately coupled to the parent squad by naming convention, and provides a simple means to elaborate similar instances through the model for vehicles. In total, there were two squads setup to represent each HMMWV in the convoy, one parent and one child squad. Together, these two squads represented a total of one vehicle and five agents in the model.

Naming convention {HMMWV PARENT SQUAD NAME}

*BlueVehicleType_VehicleNumber_*"Agent"*_InherentAgentNumber*

Example HMMWV => HMMWV_1_Agent_51

Naming convention {CHILD SQUAD NAME}

WeaponType_VehicleType_VehicleNumber

Example HMMWV Occupant Squad
=> M16_HMMWV_1

Figure 29. HMMWV Squad Naming Convention

2. Blue Force QRF Squad Representation Method

The following method was used by the team to specify and represent the squad properties for the QRF allocated to the blue force. The Red force had no similar construct. The QRF was complex because it included an ACE insertion vehicle, a set of Fire Teams, and a set of Rifle Squads. Within each set of these teams, there were multiple agent/weapon configurations requiring unique squad definitions.

A parent squad was utilized to represent both the insertion vehicle and an inherent pilot. Figure 30 depicts the naming convention associated with the allocation of rifle squads and fire teams as children to the parent insertion vehicle. The coupling of the squads establishes the parent-child relationship and thereby allows embussing to be executed in the model. The mixed weapon configuration requirements dictated that need for multiple Fire team squads and Rifle squads. For example in the model, to represent a set of two Fire Teams and three Rifle Squads one squad was required for QRF transport, four squads were required to represent the two Fire Teams, and six squads were required to represent the two Rifle Squads.

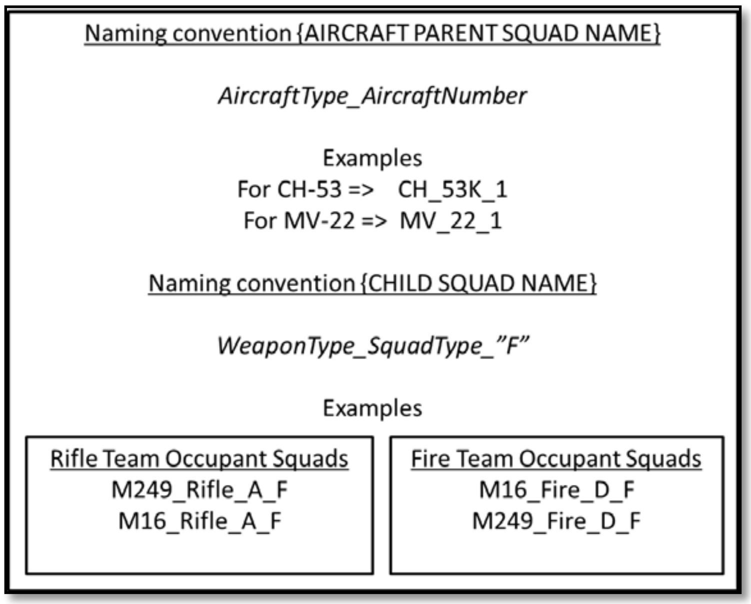


Figure 30. Aircraft Squad Naming Convention

3. Red Force Vehicle Representation Method

Red force Land Rover vehicle squads were represented in a manner similar to the HMMWV vehicles of the blue force. The parent vehicle squad and child occupant squad naming convention is shown in Figure 31. Occupant squads are discriminated by the primary weapon types they are equipped with and all vehicles are numbered. The complete Land Rover configuration consists of four vehicles each with an inherent agent and four additional occupant agents for a total of 20 red agents associated with the Land Rovers.

Naming convention {Land Rover PARENT SQUAD NAME}

RedVehicleType_VehicleNumber

Example Land Rover => Red_Truck_1

Naming convention {CHILD SQUAD NAME}

"Red"_WeaponType_VehicleNumber"T"

Example Land Rover 1 Occupant Squad
⇒ Red_AKS_74U_1T

Figure 31. Land Rover Squad Naming Convention

4. Red Force Dismounted Troops Squad Representation Method

The red force dismounted troop squads were specified according to the naming convention in Figure 32. Red force dismounted troops did not have a requirement to be part of a parent-child structure since there was no need for embussing. Conversely, all blue force troops were associated with some parent-child structure due to the need to maneuver and embuss to the local battle area.

Naming convention {RED DISMOUNT TROOP SQUAD NAME}

"Red"*_StartAgentNumber_to_EndAgentNumber*

Example Land Rover => Red_X_to_Y

Figure 32. Red Dismount Troop Squad Naming Convention

c. Agent Property Representation Techniques and Assumptions

This section elaborates all the agent properties modeling techniques and assumptions that govern how the team represented certain agent properties. MANA is considered a low resolution modeling tool. The team determined it was necessary to understand the MANA assumptions and techniques to inform analysis and conclusions. Specific agent properties areas for consideration included fuel based, armor and weapons penetration, other weapons and sensor properties, agent propensity settings and movement, and SA and communications settings.

1. Fuel Based

The fuel use rate was specified in MANA as mL/s. This required a dimensional conversion from the typically specified form of an entities fuel use rate as shown in the following equations. Fuel use specifications for the model were obtained by two methods. If a source specification was not available, then the team derived the rate using the calculation shown. Source specified use rates were available for the aircraft, taken at face value and converted to mL/s. The blue and red force vehicles (HMMWV and Land Rover) were not available. Therefore, the fuel use rates were derived as shown.

$$FuelUseRate\left(\frac{mL}{s}\right) = FuelUseRate\left(\frac{L}{hr}\right) \times 1000\left(\frac{mL}{L}\right) \times 1\frac{hr}{3600s}$$

$$FuelUseRate\left(\frac{mL}{s}\right) = 0.2778 \times FuelUseRate\left(\frac{L}{hr}\right)$$

$$FuelUseRate\left(\frac{mL}{s}\right) = 0.2778 \times FuelTankSize\left(\frac{L}{tank}\right) \times 1\frac{tank}{MaxRange(km)} \times MaxSpeed\left(\frac{km}{hr}\right)$$

The team gained further understanding regarding the specification of fuel use as follows. The model representation of fuel use was determined to be appropriate since fuel use is specified in terms of time rather than distance. This provided a realistic but low resolution model of the operational situation since aircraft and vehicles fuel use is related to operational time regardless of whether or how fast the vehicle is moving. A corollary to the method was that for an objective distance, increasing the speed would reduce the fuel use based on reduced time in route. The team recognized this was probably not entirely correct, but for the low resolution model it was more important to relate fuel use to operation time. Finally, the team observed that initial fuel fill levels were not an important aspect of the model because no re-fueling events were prescribed in the scenario and there were no situations when a vehicle or aircraft ran out of fuel. The important relationship then was the difference in initial fuel fill and ending fuel since it represented the total fuel use for that agent.

2. Armor and Weapons Penetration

The team represented agent armor and weapons penetration capability in terms of a ranking system. This was necessary because MANA had a low resolution method of representing both parameters. The objective for the modeling was to ensure that weapons armor-penetration capability was appropriately matched to the agent armor protection ability in terms of the MANA specified values. Additionally, Hits to Kill (HTK) was specified to account for the number of hits required to kill when a round was capable of penetrating. Table 16 depicts ground and air agents along with their associated armor protection values, HTK, and the weapons which can penetrate their armor. It is noteworthy that fratricide situations are possible based on the table. The team considered this an appropriate model of the operational situation.

Implicit in the table was the assumption that all weapons with same round size have same armor penetration capability. All penetration values assume maximum effective range for lethality. The handguns attributed to red and blue forces were set below body armor protection levels based on what was known about the body armor worn. Therefore, the hand guns have no lethality in the modeled battle. This was considered a deficiency since there is likely a higher HTK associated with lethality of hand guns despite the body armor configuration. MANA made this impossible to model because it does not consider the event a hit unless it penetrates the armor. Furthermore, MANA does not provide a facility to discriminate between types of hits. Aircraft armor was not well represented since in reality armor is strategically placed on aircraft. This was not a material issue for the model because aircraft were not engaged in the ground battle. If, however, a CAS mission were modeled, additional effort would be required to represent the aircraft armor as well as other countermeasures.

Table 16. Armor and Weapons Ranking

Agent	Armor	HTK	Weapons that can penetrate
Ground Forces			
HMMWV	50	10	SPG-9 (400) + above
Blue Troops	7	3	PKM (8), M240B (8) + above
Land Rover	5	5	M16A4 (6), M249 (6), AKS-74U (6) + above
Red Troops	5	3	All above
No agents	X	X	M9 Berretta (3), MP444 Bagira (3)
Aircraft			
CH-53K	5	10	Not applicable – agent not in battle
MV-22	5	10	Not applicable – agent not in battle

3. Other Weapons and Sensor Properties

Several weapons and sensor related representation issues were considered by the modeling team and discussed as follows.

MANA provides a facility to specify weapons as either primary or secondary. Additionally, up to six weapons were available for specification. The primary or secondary weapon specification along with remaining ammo and target type determined the selection criteria used by the agent at simulation run time for the battle engagement. The team specified the primary/secondary weapon configurations such that the more lethal weapon configuration was selected as primary.

The team accounted for the notion that at longer ranges a weapon is less likely to hit its target by incorporating a triangular hit rate distribution into the MANA model. Blue and red agent weapons were profiled as shown in Table 17. The red agents were given a slightly less effective distribution to simulate differences in TTP. Interpolation was specified to MANA to allow intermediate values to be generated by the software. Each weapon's shot per second model representation was specified in accordance with the actual equipment specification. All weapons apertures were specified as 360 degrees despite the fact that a 360 degree aperture implies omni-directional fires capability for vehicles and dismounts. The team determined through experimentation that a 360 degree aperture was best practice and represents a better TTP modeling of the operational experience. Ground sensor apertures were set to 120 degrees and aircraft sensors are set to 360 degrees despite the fact the aircraft sensor capability is not actionable. Randomness was not incorporated into the ground sensor detection capability due to the close quarters of the battle engagement.

Table 17. Blue and Red Force Weapons Profiles

Range	Blue Force (% Hit Rate)	Red Force (% Hit Rate)
Minimum Range	100	85
Medium Range	85	75
Maximum Range	75	50

The team represented weapons used in the ground engagement as kinetic energy weapons with the exception of the red SPG 9 mm weapon, which was configured as a high explosive weapon based on the originating specification. The team used engineering judgment to specify the SPG 9 mm weapon blast radius (10m) since no originating data was found. The SPG 9 mm was further considered to be a direct fire weapon. There were no mortars used in any of the models implemented because the team did not have sufficient time to model and debug the communications and SA requirements for indirect fires.

The team specified the aircraft weapons in the MANA models despite the fact that the aircraft did not participate in the engagement. The objective in doing so was to include knowledge gained about the aircraft weapons data into the models for future work. The GAU-17 weapon was included in the MV-22 configuration, (Defense Industry Daily Staff 2012) although the weapon is not currently available for this configuration in physical production. Additionally, the MV-22 is not currently fitted for 3000 rounds as specified in the model, but if it were, then addition of the 3000 rounds would decrease the available payload thereby reducing personnel transport capability.

4. Agent Propensity Settings and Movement

Agent behavioral settings were configured as follows. MANA uses a weighting algorithm which depends on user defined propensity settings to determine individual agent tendency to move toward or away from objects. The algorithm uses a penalty function to direct the movement taking into account distance and direction to programmable propensity objectives, namely threats, friends, neutrals, waypoints, and terrain *(McIntosh et al. 2007).*

The team utilized two of these objectives including threats and waypoints. All ground based agent propensities are set to +50 for enemy and +50 for waypoint to provide a balanced bias for movement. Aircraft is set to +50 for waypoint only since there is no battle engagement modeled for the aircraft.

Agent movement speed was configured as follows. All agent movement, whether air assets, trucks, or dismounts occurs a constant velocity within a unique simulation trigger state. MANA is capable of simulating acceleration or deceleration with piecewise velocity updates through the use of trigger states. Air assets move at the same constant velocity during the QRF insertion maneuver until they reach their last waypoint where they become stationary. Blue HMMWV ground vehicles move at a constant velocity until the enemy is observed, then reduce velocity. When the final waypoint is reached, the HMMWVs become stationary. Red Land Rover vehicles are stationary. Ground troops move slower when they observe the enemy. Random patrol modes are configured to simulate variability in the movement toward waypoints. Random patrol requires the configuration of both a variance weight factor and mean path length in meters. Settings are as follows. Blue aircraft are (10% / 10m), red and blue ground vehicles (0% / 50m), Blue ground troops from HMMWVs (20% / 50m), blue ground troops from QRF and all red ground troops (30% / 50m). These values represent random variation from the prescribed waypoint paths. The settings become moot when an enemy is classified and henceforth captures the propensity of movement from the waypoint.

The team specified a Personal Concealment factor of 50% to establish a counter-detection level. The counter-detection algorithm provides a separate means from terrain concealment and acts as a multiplication factor for concealment. This is representative of camouflage and other counter-detection capabilities typically used for wearable gear in Marine expeditions.

5. Situational Awareness and Communications Settings

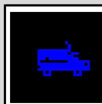
Inorganic SA and inter-squad communications were not modeled by the team. All agents were specified to have their own SA and some were specified to have squad SA such as for squads with closely coupled agents like HMMWVs. Practically, this meant that agents could see other agents solely on the basis of their sensor configuration or similar sensors of their adjacent fellow agents. Sensors are represented by the agent's ability to detect and classify a target. A detection signifies any agent has been observed, while a classification event signifies the type of agent (friend, foe, or neutral) has been observed. The team locked the detection and classification ranges at 100m for the representation of ground force sensor operations based on the close engagement that was modeled. The sensing capability represents a combination of eye sight and weapons sight, but is essentially a low resolution representation. Aircraft sensor capabilities were not actionable for the land battle.

d. Detailed Agent and Squad Specification Blue Forces

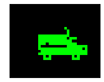
The following section provides detailed specifications for parent and child squads of both blue and red forces. The HMMWV, QRF, Land Rover, and red force dismount squad cards are provided along with hierarchy diagrams to graphically depict the parent – child relationships required for embussing.

1. HMMWV and Occupants

The HMMWV and occupants were represented with the two squads which were further specified in Figure 33 and Figure 34. The team replicated the squad specification construct and its relationship (Figure 35) as required to implement the Barra convoy patrol at each level of scale.



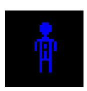
1x



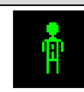
HMMWV w/ Inherent Agent

Qty	Units	Description	Trigger
95,000	ml	Initial Fill	
40	km/hr	Speed	10 km/hr
5	ml/s	Fuel Consumption	
10	Hit	Number Hits to Kill	
50%	Personal Concealment		
50	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Aperture (Field of View)	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
M240B		Primary	
M16	M9	Secondary	

Figure 33. HMMWV Parent Squad Properties



4x



HMMWV Fire Team

Qty	Units	Description	Trigger
NA	ml	Initial Fill	Debuss
5	km/hr	Speed	2 km/hr
NA	ml/s	Fuel Consumption	
3	Hit	Number Hits to Kill	
50%	Personal Concealment		
7	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Sensor Aperture	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
M16		Primary	
M9		Secondary	

Figure 34. HMMWV Child Squad Properties

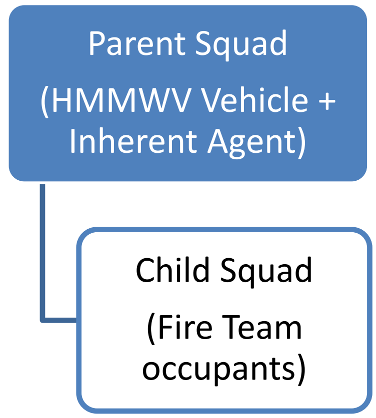
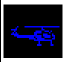


Figure 35. HMMWV Squad Hierarchy

2. QRF Insertion Vehicle and Occupants

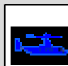
The QRF insertion vehicle and its occupants were represented with sets of squads which were further specified in Figure 36, Figure 37, and Figure 38. Like the HMMWV squads the figures represent the QRF parent and child building blocks were used to construct the full squads necessary for multiple scales. Figure 36 provides the parent CH-53K and MV-22 squad properties. Figure 37 and Figure 38 provide the child fire team and rifle squad properties. The team replicated the squad specification construct and its relationship (Figure 39) as required to implement the Barra QRF insertion at each level of scale. All weapons employed by the blue forces are specified in Table 18.



1x

CH-53K w/ Inherent Agent

Qty	Units	Description
4,698,000	ml	Initial Fill
200	km/hr	Speed
725	ml/s	Fuel Consumption
10	Hit	Number Hits to Kill
50%	Personal Concealment	
5	mm	Armor Thickness
200	m	Detect/Classify
360	deg	Sensor Aperture
0		Propensity Enemy
+50%		Propensity Waypoint
.50 Cal		Primary
.50 Cal	.50 Cal	Secondary

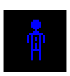


1x

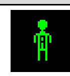
MV-22 w/ Inherent Agent

Qty	Units	Description
6,513,000	ml	Initial Fill
200	km/hr	Speed
464	ml/s	Fuel Consumption
10	Hit	Number Hits to Kill
50%	Personal Concealment	
5	mm	Armor Thickness
200	m	Detect/Classify
360	deg	Sensor Aperture
0		Propensity Enemy
+50%		Propensity Waypoint
GAU -17 MiniGun		Primary
.50 Cal		Secondary

Figure 36. QRF Parent Squad Properties CH-53 and MV-22

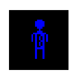


4x

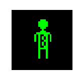


QRF Fire Team Squad

Qty	Units	Description	Trigger
NA	ml	Initial Fill	
5	km/hr	Speed	2 km/hr
NA	ml/s	Fuel Consumption	
3	Hit	Number Hits to Kill	
50%	Personal Concealment		
7	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Sensor Aperture	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
M16		Primary	
M9		Secondary	



1x



QRF Fire Team Squad

Qty	Units	Description	Trigger
NA	ml	Initial Fill	
5	km/hr	Speed	2 km/hr
NA	ml/s	Fuel Consumption	
3	Hit	Number Hits to Kill	
50%	Personal Concealment		
7	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Sensor Aperture	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
M249		Primary	
M9		Secondary	

Figure 37. QRF Child Squad Properties, Fire Team

6x

QRF Rifle Squad

Qty	Units	Description	Trigger
NA	ml	Initial Fill	
5	km/hr	Speed	2 km/hr
NA	ml/s	Fuel Consumption	
3	Hit	Number Hits to Kill	
50%	Personal Concealment		
7	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Sensor Aperture	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
M16		Primary	
M9		Secondary	

2x

QRF Rifle Squad

Qty	Units	Description	Trigger
NA	ml	Initial Fill	
5	km/hr	Speed	2 km/hr
NA	ml/s	Fuel Consumption	
3	Hit	Number Hits to Kill	
50%	Personal Concealment		
7	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Sensor Aperture	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
M249		Primary	
M9		Secondary	

Figure 38. QRF Child Squad Properties, Rifle Squad

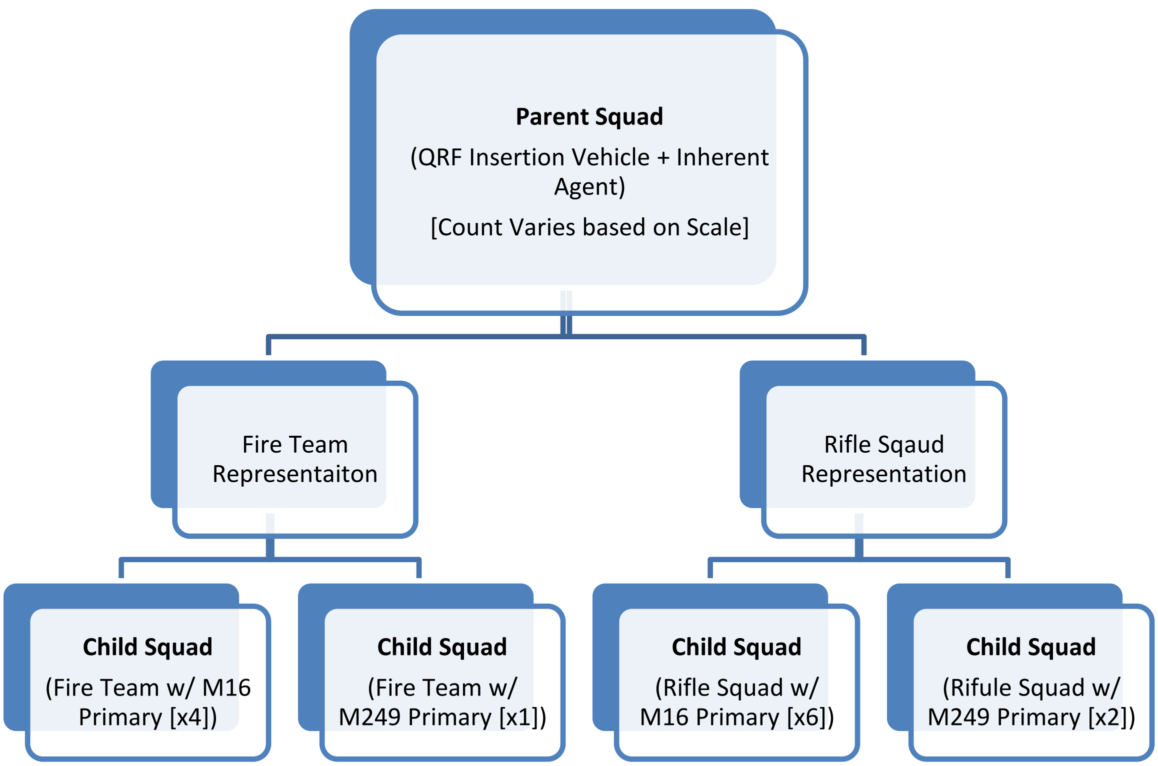


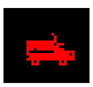
Figure 39. QRF Squad Hierarchy

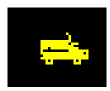
Table 18. Blue Agent Weapons Properties

BLUE AGENT WEAPONS			
Weapons	**Details**		
M16A4 (5.56mm)	Shots per Second		0.2
	Armor Penetration		6mm
	Shots/Ammo		60
Range (m)	1	275	550
Prob of Hit	1	0.85	0.75
M9 (9mm)	Shots per Second		0.17
	Armor Penetration		3mm
	Shots/Ammo		30
Range (m)	1	25	50
Prob of Hit	1	0.85	0.75
M249 (5.56mm)	Shots per Second		1.4
	Armor Penetration		6mm
	Shots/Ammo		200
Range (m)	1	500	1000
Prob of Hit	1	0.85	0.75
M240B (7.62mm)	Shots per Second		0.6
	Armor Penetration		8mm
	Shots/Ammo		200
Range (m)	2	900	1800
Prob of Hit	1	0.85	0.75
50 Cal	Shots per Second		0.7
	Armor Penetration		21mm
	Shots/Ammo		200
Range (m)	2	915	1829
Prob of Hit	1	0.85	0.75
GAU-17 (7.62mm) MINI GUN	Shots per Second		66.67
	Armor Penetration		6mm
	Shots/Ammo		3000
Range (m)	15	547	1093
Prob of Hit	1	0.85	0.75

e. Detailed Agent and Squad Specification Red Forces

Enemy squad specifications for Land Rover vehicles and their occupants are shown in Figure 40 and Figure 41. Like the HMMWV construct this construct was replicated for the four Land Rovers in the red force to implement the stationary Land Rover configuration and associated parent-child relationship (Figure 42). The replication was not performed pursuant to model scale factoring, since the red force level remained constant for all model scales. Red force dismount troop squad properties are detailed in Figure 43. These troops have no parent or child association based on the CONEMP. Like the Land Rover squads red force dismount squads were not required to be implemented at various levels of scale. Therefore, the specifications shown represent the actual squads rather than notional squads that were replicated across the model scales like the blue forces. All weapons employed by the red forces and squad agent counts are specified in Table 19.



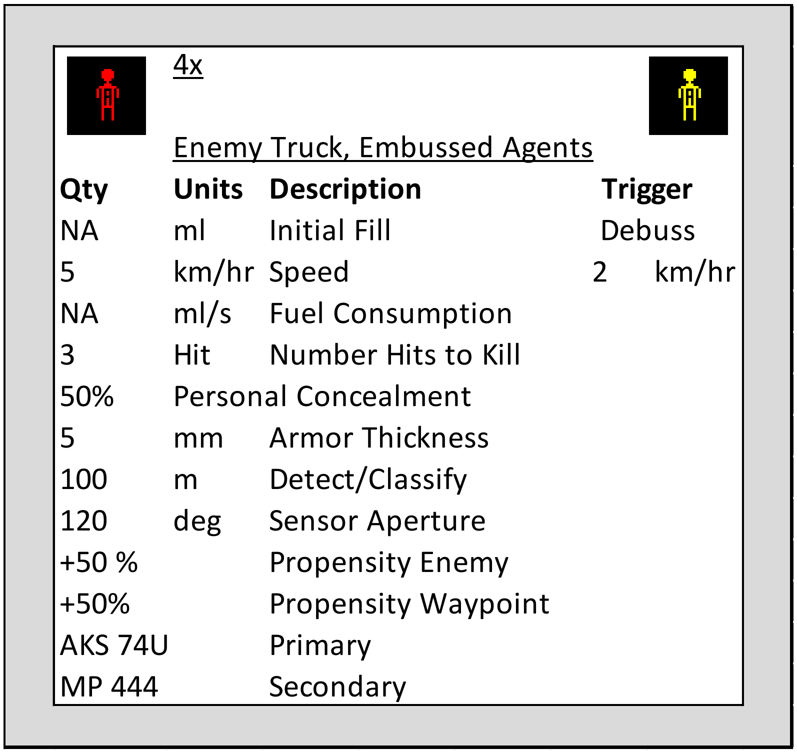


1x

Land Rover ™

Qty	Units	Description	Trigger
75000	ml	Initial Fill	
0	km/hr	Speed	0 km/hr
5	ml/s	Fuel Consumption	
5	Hit	Number Hits to Kill	
50%	Personal Concealment		
5	mm	Armor Thickness	
100	m	Detect/Classify	
120	deg	Sensor Aperture	
+50%		Propensity Enemy	
+50%		Propensity Waypoint	
SPG 9	or PKM	Primary	
AKS 74U	MP 444	Secondary	

Figure 40. Land Rover Parent Squad Properties



4x

Enemy Truck, Embussed Agents

Qty	Units	Description	Trigger	
NA	ml	Initial Fill	Debuss	
5	km/hr	Speed	2	km/hr
NA	ml/s	Fuel Consumption		
3	Hit	Number Hits to Kill		
50%	Personal Concealment			
5	mm	Armor Thickness		
100	m	Detect/Classify		
120	deg	Sensor Aperture		
+50 %		Propensity Enemy		
+50%		Propensity Waypoint		
AKS 74U		Primary		
MP 444		Secondary		

Figure 41. Land Rover Child Squad Properties

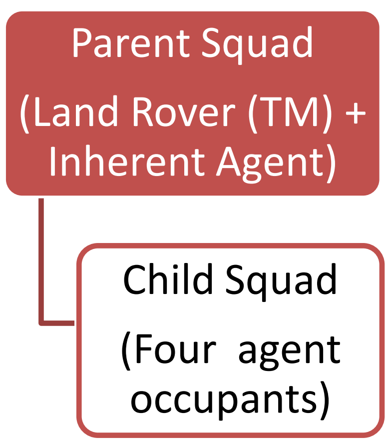
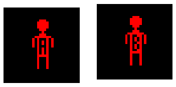
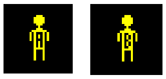


Figure 42. Land Rover Squad Hierarchy





Red Squads, Ground Force

Qty	Units	Description		Trigger
NA	ml	Initial Fill		
5	km/hr	Speed		2 km/hr
NA	ml/s	Fuel Consumption		
3	Hit	Number Hits to Kill		
50%	Personal Concealment			
5	mm	Armor Thickness		
100	m	Detect/Classify		
120	deg	Sensor Aperture		
+50%		Propensity Enemy		
+50%		Propensity Waypoint		**Squad Agent Count**
PKM	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	8
PKM	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	7
AKS74U	Primary	MP444	Secondary	7
AKS74U	Primary	MP444	Secondary	7
AKS74U	Primary	MP444	Secondary	6
AKS74U	Primary	MP444	Secondary	9

Figure 43. Enemy Squads, Ground Force Properties

Table 19. Red Agent Weapon Properties

RED AGENT WEAPONS			
Weapons	**Details**		
AKS 74 U (5.45mm)	Shots per Second		1.67
	Armor Penetration		6mm
	Shots/Ammo		45
Range (m)	1	200	400
Prob of Hit	0.85	0.75	0.5
MP 444 (9mm)	Shots per Second		0.5
	Armor Penetration		3mm
	Shots/Ammo		15
Range (m)	1	25	50
Prob of Hit	0.85	0.75	0.5
PKM (7.62mm)	Shots per Second		4.17
	Armor Penetration		8mm
	Shots/Ammo		250
Range (m)	2	500	1000
Prob of Hit	0.85	0.75	0.5
SPG 9 (73mm)	Shots per Second		0.17
	Armor Penetration		400mm
	Shots/Ammo		1
Range (m)	100	650	1300
Prob of Hit	0.85	0.75	0.5

6. Mission Sequence Representation

Chapter IV.D.4 and Chapter IV.D.5 established the high level background and terrain maps as well as squad and agent properties providing the necessary modeling to establish a context in which the operational scenario could be further modeled. Operational modeling was performed by giving the squads and their agents an activity framework that represented the CONOP specified by SE process.

The team established an activity framework by defining squad starting points (home boxes), movement paths (way points), and destinations (objective areas) and then scripting a sequence for the evolution of the scenario. The timeline shown in Figure 44 depicts the time sequence for the scenario. This basic timeline was replicated in each of the three scaled models. The squads of each model were given an activity map, the aggregate of which creates the activity framework. The narratives that follow describe the activity details of each type of squad to support the scripted timeline. In the actual models there were many more squads which are not described in this report. A representative or notional example is therefore depicted when appropriate. Squad activity maps are all presented in Appendix E.

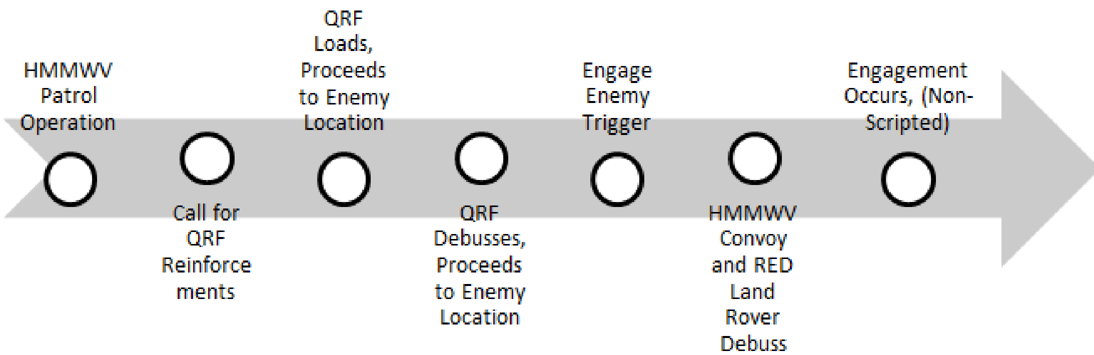


Figure 44. Scenario Timeline Representation

a. HMMWV Convoy Patrol Activity Map

The HMMWV convoy patrol activity map supported the embussing of squads as they patrolled through the city of Barra along planned routes. This scripted behavior was represented using home boxes and waypoints as depicted in Appendix E. Figure 85 represents one of up to four possible HMMWV activity maps specified in the three models. Home boxes, which determine the initial positioning of the HMMWV squads, were represented as a 2-meter by 2-meter box. The planned path for a HMMWV was specified through a series of waypoints emplaced on the figure in reverse order. The activity involves the HMMWV squad starting at the home box and immediately preceding to the first waypoint counting down toward the final objective area, labeled with a zero. The home box is shown as "H0" and the waypoints begin with the highest value "57" and count down to the ultimate objective "0." Each HMMWV specified for the convoy in each model followed a similar set of waypoints to similar objective areas. The HMMWV activity also represents the initial activity in the MANA model timeline.

b. HMMWV Debuss to Battle Activity Map

Once the HMMWV squad detected enemy squads located in and around the enemy compound the occupant squad debussed and immediately maneuvered to the objective area shown in Figure 86 in Appendix E. This objective area was set to the center of the enemy location.

c. QRF Insertion Activity Map

The QRF insertion activity map supported the embussing of QRF squads to the landing zones near the enemy location as shown in Figure 87 in Appendix E. The QRF insertion vehicle, either a CH-53K or MV-22 depending on the model in question, followed the notional path shown in the figure. Similar activity map paths are provided for each model and landing zone required for the ACE. At the beginning of the scenario timeline, the QRF was located at home box "H0" and was scripted to delay. This was used to simulate the HMMWV convoy SALUTE to command and subsequent C3 coordination of QRF assets. The delay was utilized so the QRF and HMMWV convoy arrived at the engagement area at a similar time. The scripted simultaneous arrival method was used as a work around to model the situation where the HMMWV would provide screening prior to arrival of the reinforcements. The QRF insertion vehicle was embussed with the QRF fire teams and rifle squads and set to debuss upon arrival at the objective area "0."

d. QRF Landing to Battle Activity Maps

Once the QRF insertion vehicle reached its final waypoint, the aircraft squad debussed all occupant squads. To represent the tactics planned in the CONOP the QRF landing to battle activity was defined with a set of north and south routes into the enemy location. A notional north and south route are depicted in the activity maps in Figure 88 and Figure 89 in Appendix E. In the actual scale models several north and south routes were required to support the fire teams and rifle squads required by the QRF configuration.

e. Land Rover Squad Activity Maps

Four stationary enemy Land Rover vehicles were placed on the northern side of the enemy location. Figure 90 in Appendix E shows one of the four Land Rover home boxes. There are no waypoints or objective areas applicable for any of the Land Rover vehicles since they do not move. Land Rover activity maps are identical for each of the three scale models. The Land Rover occupant squads and associated waypoint path are shown in Figure 91. Debussing from the Land Rover occurs upon detect and classify of blue force agents from the HMMWVs. The team implemented four unique debussing waypoint paths and objectives, one for each of the four Land Rovers. All three scale models are identical with respect to the Land Rover waypoint paths.

f. Red Force Ground Squad Activity Maps

Twelve red force dismounted ground squad activity maps were created to provide full scripting of the red force dismount activity. Two example activity maps are shown in Figure 92 and Figure 93 in Appendix E.

g. Top Level Activity Sequence

Four top level activity maps are shown in Appendix E to depict a simulation sequence of start, mid-HMMWV patrol, mid-QRF insertion, and battle engagement. The sequence shown provides insight to the partitioning of scripted and autonomous activity which the team implemented. In particular the first three figures represent completely scripted behavior necessary to setup the conditions for the autonomous activity in the fourth figure. The initial conditions shown in Figure 94 represent the initial blue and red force employment at their respective home boxes. The next sequence point shown in Figure 95 represents a mid-HMMWV patrol point where the convoy is proceeding with a screen operation. The third point in the sequence, shown in Figure 96, represents an ACE QRF insertion timed with the HMMWV patrol in such a manner to script simultaneous arrival of forces to the engagement area. Finally, the fourth sequence, shown in Figure 97, defines the partition point between the scripted behavior and the autonomous battle engagement behavior.

h. Other Activity Considerations

Trigger states were defined to establish a default state, alter personality at point of enemy contact, and alter personality at point of debussing. The default state governed personality until and unless one of the other states caused a personality change. Conversely, the default state was resumed when those conditions ceased to exist. Figure 45 depicts the color coding associated with personality changes during enemy contact. Blue agents with red agent SA change to green. Conversely, red agents with blue agent SA change to yellow. Casualty agents were rotated sideways. The visual representation in the MANA GUI improved debugging and helped ensure that SA and trigger states were properly setup. The trigger state associated with the point of debussing prompted the release of occupant squads from HMMWV and Land Rover squads upon enemy contact. Besides color changes, other personality changes included changes to agent maneuver speed to simulate a tactical approach to battle.

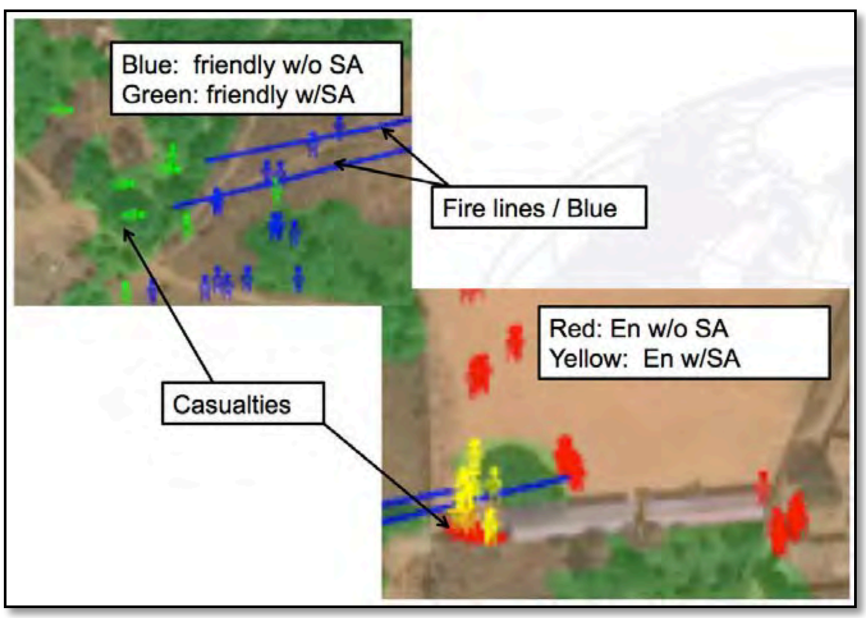


Figure 45. Squad Enemy Contact Personality Changes

7. Reconciliation of Segment Specification to Modeling

a. Marine Corps Task Functionality

Table 20 reconciles the specified functionality of the notional system with what was actually modeled using MANA. Four levels of compliance were established included yes, no, partial, and implied. Yes/no provided an indication of whether the function was implemented in whole or not at all. Partial indicated adequate elements of the function were implemented, but not all levels of the functionality were present. C2 sequences were a common problem and therefore resulted in partial implementation. Implied compliance indicated that the functionality was scripted into the simulation. The team was able to demonstrate limited targeting and maneuver capability as well as direct fires with the MANA experiments over three levels of scale. While this provided a minimum level of battle effectiveness coupled with the energy driver of the QRF insertion maneuver, the team did not consider the modeling complete, because key energy drivers of the scenario were not included. The team consequently developed a supplemental energy driver analysis strategy to support the tradespace study as shown in the notes column of Table 20. Chapter V.C provides the supplemental energy link analysis.

Table 20. MANA Modeled Functionality Reconciliation

MCT Ref.	Task	MANA	Energy Link Analysis	Notes
MCT 1.3.4.1.1	Post mission blue extraction	No	Yes	No MANA post mission. Energy analysis considers post mission extraction.
MCT 1.6.5.11	QRF airborne insertion	Yes	Yes	Complete MANA simulation, also in energy analysis.
MCT 1.6.11.3	Convoy screen operations	Partial	Yes	Convoy patrol/maneuver modeled in MANA, no SA reporting for SALUTE. Defensive posture through timed QRF arrival scripting. Energy analysis also considers convoy fuel use.
MCT 2.1.1.5	Targeting support	Partial	No	Organic targeting only represented in MANA. No indirect fire support.
MCT 2.1.1.6	Combat assessment (BDA)	No	Yes	Actionable BDA is not supported in MANA at simulation run-time. Energy analysis considers casualty rates post mission to infer casualty evacuation requirements.

MCT Ref.	Task	MANA	Energy Link Analysis	Notes
MCT 3.2.3.1.1	CAS	No	Yes	No MANA modeling in this iteration. Energy analysis considers energy cost as function of battle time.
MCT 3.2.4.1	Direct fires	Yes	No	Complete MANA simulation (key part of effectiveness measurement).
MCT 3.2.4.2	Indirect fires	No	No	No MANA modeling in this iteration.
MCT 4.3.8	Air logistics (supply)	No	Yes	No MANA modeling in this iteration. Energy analysis considers energy cost for air logistics.
MCT 4.5.5	Casualty evacuation	No	Yes	No MANA modeling in this iteration, but could be through embussing if actionable BDA was available. Energy analysis considers energy cost from post mission casualty data.
MCT 5.3.1.2	Tactical C2	Implied	No	MANA modeling implies C2 sequences for model progression through scripting of QRF C2.
MCT 5.3.4.4	Coordinate ground fires	Implied	No	MANA modeling implies C2 coordination for ground fires through tactical movement associated with fire team and rifle squad routes.
MCT 5.3.4.5	Coordinate CAS	No	No	No MANA modeling in this iteration.
MCT 6.1.1.5.3	Patrolling	Yes	Yes	Convoy patrol/maneuver modeled in MANA. No additional patrols required or patrolled. Energy analysis also considers convoy fuel use.

E. MODEL OUTPUT CONSIDERATIONS

1. MANA Output Processing

a. MANA Data Output Facility

MANA provides an output data facility that generates Comma Separated Value (CSV) files for subsequent data harvesting and analysis. A data package was created from multiple runs and for each scale model through the use of batch processing. MANA supports end of run data types and step data (time series), although the team utilized the end of run data only. The data output options shown in Table 21 each represented a separate CSV output file or set of files containing data for every replication of the experiment. The table indicates the three key output files sets from which the team obtained the MANA metrics. The modeling team had the task of determining how to support the SE MOEs and develop additional energy metrics with the available MANA output data.

Table 21. MANA Data Output File Application

Data File(s)	Useful Data
Multi-Run Summary File	Battle Length
Record Step by Step Data	Not used
Record Casualty Location Data	Fratricide
Record Agent State Data	Fuel, Casualty
Record Detections	Not used
Record Multi-Contact Detections	Not used
Record Positions	Not used
Record Red Detections per Time Step	Not used
Record COMS per Time Step	Not used
Record First Enemy Detections	Not used

b. MANA Experiments Replication Requirements

The team concluded the DOE in Chapter IV.E with the finding that three design points representing three levels are scale were appropriate to examine an operational energy and operational effectiveness tradespace. While this experiment design process determined the configuration and values associated with input factors of the three executable models, experimental replication repeats the execution of each of those unique design points enough times so that the statistics of the resulting data are stable. In a study of 22 Monte Carlo simulations, Mundfrom et al. (2011) examined replication requirements and made the following observations.

> No empirically-based recommendations regarding the required number of replications exist.
>
> In all but two of the situations in which more replications than what was used originally were needed, the original studies began with 1,000 or fewer replications. (Mundfrom et al. 2011)

> In general, for most of the studies replicated and most of the statistics calculated, the minimum recommended number of replications was always less than 10,000 and in many cases was less than 5,000.

Guided by Mundfrom, et al., the team performed trials to examine the stability of frequency data associated with MANA output and to determine an appropriate replication count. Replications of 100, 500, 1000, and 2500 were performed with the result that frequency data was stable between 500 and 1000 runs. On that basis the team accepted 1000 runs as the correct replication count for each of the three scale models (Mundfrom et al. 2011).

2. Meta-Modeling

a. MANA Output Data Harvesting

The team developed a MATLAB script to read in the MANA output files associated with a 1000 run data set, harvest the key metrics shown in Table 22, and output the results to a single file. The script operated on the Agent State CSV files, Casualty Location Results CSV files, and the MANA Multi-Run Summary output file as follows.

The Agent State CVS files for each run were read in and the following parameters tabulated by run number: Fuel data for each of the blue vehicles, Blue and Red (Injured, Dead, Active), remaining ammo, and total hits incurred by each force. Aggregate totals across agents were generated for casualty, hits, and ammo data. Fuel use data was output for each vehicle. Fratricide data was obtained from the Casualty Location Results CSV file by examining the shooter in each case of a kill and appropriately classifying and tabulating blue and red fratricide events.

The Multi-run Summary file was examined for battle length and results tabulated for output. The end result of the harvesting script was a single file with all the parameters listed in Table 22 replicated 1000 times to represent the 1000 runs of the model. The process was repeated for each of the three scale models resulting in three files each of which contained 20 parameters multiplied by 1000 rows of replication data.

Table 22. MANA Harvest Data Output Metrics

Applies to model			Metric	Units	Notes
1	2	3			
X	X	X	Remaining Fuel HMMWV 1	mL	Initial fill – remaining = fuel used
X	X	X	Remaining Fuel HMMWV 2	mL	
X	X	X	Remaining Fuel HMMWV 3	mL	
		X	Remaining Fuel HMMWV 4	mL	
X	X	X	Remaining Fuel CH-53K 1	mL	
		X	Remaining Fuel CH-53K 2	mL	
	X	X	Remaining Fuel MV-22	mL	
X	X	X	Blue Injured	Qty.	Aggregate Total = injured + active + dead
X	X	X	Blue Dead	Qty.	
X	X	X	Blue Active	Qty.	
X	X	X	Blue Total Hits	Qty.	Aggregate total rounds that hit blue agents
X	X	X	Red Injured	Qty.	
X	X	X	Red Dead	Qty.	
X	X	X	Red Active	Qty.	Non-injured
X	X	X	Red Total Hits	Qty.	
X	X	X	Blue Ammo Remaining	Qty.	Initial – remaining = used ammo
X	X	X	Red Ammo Remaining	Qty.	
X	X	X	Blue Fratricide	Qty.	
X	X	X	Red Fratricide	Qty.	
X	X	X	Battle Length	sec	

b. MANA Metrics

Some measures were computed from the MANA harvested data prior to performing statistical analysis. Others were combined, and/or used directly to support the SE measures determination in Chapter III. This section describes the construction from and application of the MANA metrics, and the resulting metrics which were designated for statistical analysis. Final MANA metrics were designated with a letter "X" in front of the metric number as shown in Table 23.

1. Fuel Parameters

Each of the ground vehicle and aircraft fuel measures were maintained in-tact for statistical examination to allow visibility into separate agent fuel use. Each fuel measure was subject to an offset formula based on the initial fill parameter to obtain total fuel used in the mission and converted from mL to L.

Fuel Conversion (X1-X7)

$$MissionFuelUseForVehicle(L) = (InitialFill - RemainingFuel)(\text{mL}) \times \left(\frac{L}{1000mL}\right)$$

2. Casualty and Fires Data

Four formulae guided the conversion of MANA data for casualty and fires data. The ammo metrics were subject to an offset conversion to determine the used ammo from the starting and ending values. Two Loss Exchange Ratios were constructed as a measure of the relative loss between the forces as a fraction of their total troops. The first ratio accounts for casualty (dead) loss while the second includes casualties and injured. Fires efficiency metrics were constructed to measure the ability of each force to direct fire and hit the other force. A blue force injury rate was constructed to track the blue injuries as a percentage of total blue force. There was no similar red force injury metric included.

Ammo Offset (X16, X17)

$$AmmoUsed = InitialAmmo - RemainingAmmo$$

Loss Exchange Ratios (X21 X22)

$$LossExchangeRatioC = \frac{\frac{BlueDead}{TotalBlue}}{\frac{RedDead}{TotalRed}} \times 100\%$$

$$LossExchangeRatioI = \frac{\frac{BlueDead + BlueInjured}{TotalBlue}}{\frac{RedDead + RedInjured}{TotalRed}} \times 100\%$$

Fires Efficiency Metrics (X23, X24)

$$BlueFiresEfficiency = \frac{RedHits}{BlueAmmoUsed} \times 100\%$$

$$RedFiresEfficiency = \frac{BlueHits}{RedAmmoUsed} \times 100\%$$

Blue Injury Rate (X25)

$$BlueInjuryRate = \frac{BlueInjured}{TotalBlue} \times 100\%$$

3. Battle Length

The battle length measure in seconds provided a key metric based on the energy drivers associated with battle length. The team utilized MANA's facility for setting the end of run criteria based on an ending Red Dead value of 85. This value was prescribed through experimentation in all three models. The team discovered that setting the value too close to 100 (the maximum Red agents) would result in excessively long simulations due anomalous movement and SA behavior of the last few agents.

4. Final MANA Metrics

Table 23 represents the final list of metrics which originated from the MANA output data, converted, constructed, and made suitable for further analysis. This list is intended to be reconciled with the SE measures, subjected to descriptive statistical analysis, and finally combined with energy link analysis in Chapter V.

Table 23. Final MANA Metrics

Applies to model			Metric	Units	Metric Number
1	2	3			
X	X	X	HMMWV 1 Fuel Consumed	L	X1
X	X	X	HMMWV 2 Fuel Consumed	L	X2
X	X	X	HMMWV 3 Fuel Consumed	L	X3
		X	HMMWV 4 Fuel Consumed	L	X4
X	X	X	CH-53K 1 Fuel Consumed	L	X5
		X	CH-53K 2 Fuel Consumed	L	X6
	X	X	MV-22 Fuel Consumed	L	X7
X	X	X	Blue Injured	Qty.	X8
X	X	X	Blue Dead	Qty.	X9
X	X	X	Blue Active	Qty.	X10
X	X	X	Blue Total Hits	Qty.	X11
X	X	X	Red Injured	Qty.	X12
X	X	X	Red Dead	Qty.	X13
X	X	X	Red Active	Qty.	X14
X	X	X	Red Total Hits	Qty.	X15
X	X	X	Blue Ammo Used	Qty.	X16
X	X	X	Red Ammo Used	Qty.	X17
X	X	X	Blue Fratricide	Qty.	X18
X	X	X	Red Fratricide	Qty.	X19
X	X	X	Battle Length	sec	X20
X	X	X	Loss Exchange Ratio (Casualty)	%	X21
X	X	X	Loss Exchange Ratio (Casualty and Injured)	%	X22
X	X	X	Blue Fires Efficiency	%	X23
X	X	X	Red Fires Efficiency	%	X24
X	X	X	Blue Injury Rate	%	X25

5. MANA Metric – SE MOE Reconciliation

MANA metrics represent a portion of the total metrics necessary to construct the tradespace. This section describes what was accomplished in terms of the MOEs specified by the engineering team to holistically address all six dimensions of the war fighting spectrum. Table 24 lists all MOEs specified by the SE team and the degree to which the MANA metrics fulfilled those MOEs. In some cases the MANA modeling prescribed a solution to the CONOP and the metric only represents an assumption. Other cases are satisfied or augmented through the MANA output metrics construction described herein. Finally, some MOEs requested by SE simply are not supported at all by the MANA modeling. The table contains a “Method” column which is coded as (acquired, prescribed, or N/A) to indicate whether the MANA models generated the output, were specified the value as an assumption, or the metric was not applicable at all. Notes are included for each MANA model to provide compliance details. The team reviewed the reconciliation and concluded that MANA metrics provided key warfighting MOE support for fires and casualty data, but very little additional data was available to support other dimensions of the warfighting spectrum.

Table 24. MANA Metrics to SE MOE Reconciliation (after United States Marine Corps 2014)

MCT Area			**Method**	**MANA 1**	**MANA 2**	**MANA 3**
MCT 1.3.4.1.1 Conduct Airborne Rapid Insertion/Extraction						
M8	Time	To provide extraction operation.	N/A	N/A	N/A	N/A
MCT 1.6.5.11 Conduct Quick Reaction Force Operations						
M1	Percent	Force required for Quick Reaction Force operations.	Prescribed	QRF / 3-Platoon	QRF / 4-Platoon	QRF / 5-Platoon
M2	Time	Quick Reaction Force reaction time. (does not include Sea-Base)	Prescribed	4 min	5 min	6 min
MCT 1.6.11.3 Conduct Screen Operations						
M3	Percent	Of enemy troops detected before they could come into contact with friendly flanks or rear areas.	Prescribed	100	100	100

MCT Area			Method	MANA 1	MANA 2	MANA 3
M4	Percent	Of enemy troops detected which were engaged by fire support or maneuver assets before they could come into contact with friendly flanks or rear areas.	Prescribed	100	100	100
MCT 2.1.1.5 Support Targeting						
M1	Y/N	Targets assigned relative value.	N/A	Adv. weapon	Adv. weapon	Adv. weapon
M3	Percent	Of targets available for striking.	N/A	Adv. SA	Adv. SA	Adv. SA
M4	Percent	Of prioritized targets collected upon.	N/A	Adv. weapon	Adv. weapon	Adv. weapon
M9	Y/N	Maintain display of current enemy situation with target locations and priorities.	N/A	Adv. SA	Adv. SA	Adv. SA
M14	Incidents	Of Blue-on-Blue engagements.	Acquired	X18	X18	X18
MCT 2.1.1.6 Support Combat Assessment						

MCT Area			Method	MANA 1	MANA 2	MANA 3
M1	Percent	Of struck targets assigned collection assets.	N/A	N/A	N/A	N/A
M5	Y/N	Intelligence capable of being acquired to support Assessment (e.g., COMCAM, Imagery, SIGINT, HUMINT, CA, etc.).	Acquired	Yes, Post mission BDA	Yes, Post mission BDA	Yes, post mission BDA
MCT 3.2.3.1.1 Conduct Close Air Support (CAS)						
M4	Number	Of sorties daily sustained during contingency/combat operations.	N/A	N/A	N/A	N/A
M7	Percent	Of enemy targets engaged.	N/A	N/A	N/A	N/A
M8	Percent	Of targets attacked with desired effects.	N/A	N/A	N/A	N/A
M10	Percent	Of friendly forces covered by CAS.	N/A	N/A	N/A	N/A
M12	Number/Percent	Incidents of fratricide.	N/A	N/A	N/A	N/A
M17	Percent	Of weapons effects on target (percent of desired effects achieved).	N/A	N/A	N/A	N/A

MCT Area			Method	MANA 1	MANA 2	MANA 3
MCT 3.2.4.1 Conduct Direct Fires						
M1	Percent	Of targets attacked with desired effects.	Acquired	X12~X15	X12~X15	X12~X15
M4	Number	Incidents of fratricide while attacking targets in support of operational maneuver.	Acquired	X18, X19	X18, X19	X18, X19
M5	Y/N	Take the enemy under fire using lethal and nonlethal gunfire delivered on target.	Acquired	yes	yes	yes
M6	Number	Of missions completed.	Prescribed	1, defined stop = 85 Red kill	1, defined stop = 85 Red kill	1, defined stop = 85 Red kill
MCT 3.2.4.2 Conduct Indirect Fires						
M1	Percent	Of targets attacked with desired effects.	N/A	N/A	N/A	N/A
M4	Number	Incidents of fratricide while attacking targets in support of operational maneuver.	N/A	N/A	N/A	N/A

MCT Area			Method	MANA 1	MANA 2	MANA 3
M6	Y/N	Apply indirect fire, ground-based weapon systems.	N/A	N/A	N/A	N/A
MCT 4.3.8 Conduct Air Logistic Support						
M5	Number	Of sorties daily sustained during contingency/combat operations.	N/A	N/A	N/A	N/A
M8	Percent	Of required support material distributed at the time and place required.	N/A	N/A	N/A	N/A
MCT 4.5.5 Conduct Casualty Evacuation						
M6	Hours	From wound or injury until person is in surgery or other appropriate care.	N/A	N/A	N/A	N/A
M8	Percent	Of casualty death.	N/A	N/A	N/A	N/A
MCT 5.3.1.2 Exercise Tactical Command and Control						
M1	Time	For units to respond to tasking.	Prescribed	0, QRF maneuver	0, QRF maneuver	0, QRF maneuver
M2	Time	Delay in response to orders.	Prescribed	0, QRF maneuver	0, QRF maneuver	0, QRF maneuver
M3	Percent	Of units responding appropriately to orders.	Prescribed	100, QRF1	100, QRF2	100, QRF3

MCT Area			Method	MANA 1	MANA 2	MANA 3
MCT 5.3.4.4 Coordinate Ground Surface Fires						
M1	Number	Of targets successfully engaged.	Prescribed	stop condition = 85 Red kill	stop condition = 85 Red kill	stop condition = 85 Red kill
M4	Number	Of fires on friendly/neutral forces.	Acquired	Estimated X18 * HTK	Estimated X18 * HTK	Estimated X18 * HTK
MCT 5.3.4.5 Coordinate Close Air Support (CAS)						
M3	Percent	Of friendly aircraft lost per sortie.	N/A	N/A	N/A	N/A
M5	Number	Of fires on friendly/neutral forces.	N/A	N/A	N/A	N/A
M6	Percent	Of enemy units detected, were engaged.	N/A	N/A	N/A	N/A
M7	Percent	Of enemy units engaged, were downed.	N/A	N/A	N/A	N/A
M8	Minutes	Of on-station time of CAS support.	N/A	N/A	N/A	N/A
MCT 6.1.1.5.3 Conduct Patrolling						

MCT Area			Method	MANA 1	MANA 2	MANA 3
M1	Incidents	Of friendly operations degraded due to enemy observation, detection, interference, espionage, terrorism and/or sabotage.	Prescribed	1, Convoy Screen interruption	1, Convoy Screen interruption	1, Convoy Screen interruption
M2	Incidents	By enemy troops, or partisans, affecting security of force and means in the operations area.	Prescribed	1 Convoy Screen interruption	1 Convoy Screen interruption	1 Convoy Screen interruption
M9	Y/N	Urban patrolling conducted.	Prescribed	Yes	Yes	Yes

3. Statistical Metrics

a. Descriptive Statistics

The team subjected the select MANA metrics to statistical processing using JMP 11. Descriptive statistical metrics were selected to gain insight into the random distribution of the data which results from certain random variable inputs as well as autonomous activity present in each of the scale simulations. The MANA metrics were statistically described for the 1000 runs of each of the three scale models using the following statistical metrics.

- Frequency Distribution (includes Normal fit, Box plot, outliers)
- Quantiles
- Summary Statistics (Mean, STD Dev, STD Err Mean, 95% CI)

b. Analysis of Variance

Certain data from the Final MANA output metrics were used to perform the Analysis of Variance (ANOVA) described in Chapter V. Specifically, a one-way (three level) ANOVA was performed to gain insight into the variability of data within and between the three levels represented by the data output of the three MANA scale models.

F. DESIGN OF EXPERIMENTS

1. Experimental Process

Russell R. Barton defines an experimental process and planning sequence for conduct of experimentation that the team employed for the MANA experiments (Barton 2004). Both processes shown in Figure 46 are elaborated through the experimental planning phase to demonstrate how the team arrived at the experimental design of three scaled 1st Company Platoon configurations. Experimental execution is described along with model output considerations in Chapter IV.E. Analysis of data is the subject of the AoA presented in Chapter V. A presumption of the experimental process elaboration is that the basic modeling of the notional system in an operational context specified by the SE team has been completed. The team executed the experimental process to determine configurations of the model that would provide adequate data for tradespace analysis, not prescribe its design (Barton 2004).

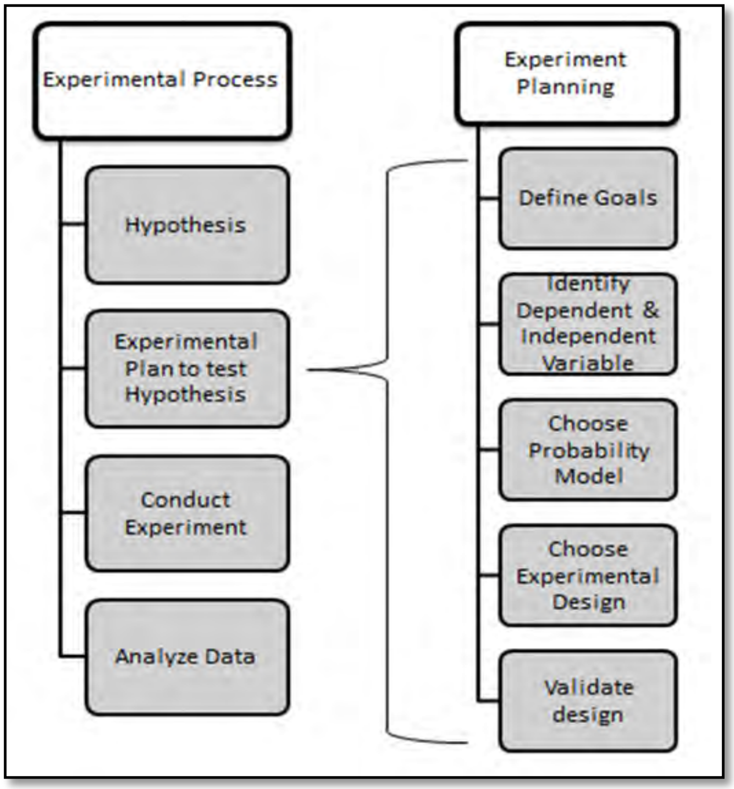


Figure 46. Experimental and Planning Process (after Barton 2004)

Chapter I proposed a set of research questions which allowed the team to pursue the OE2 line of inquiry. Implicit in the original research questions were hypotheses which are suitable to form a basis for experimentation. An examination of each research question was performed and the associated hypothesis stated if it existed.

a. Experimental Hypothesis One

Question one asked: "What is the energy cost associated with execution of a successful USMC expeditionary mission?" The team hypothesized that there was a discoverable threshold energy cost associated with the execution of a successful USMC expeditionary mission. That is, there is an energy cost below which the mission will fail and above which the mission will succeed.

b. Experimental Hypothesis Two

Question two asked: "What are the impacts of variations in MEB scaling on Operational Effectiveness and Operational Energy?" The team hypothesized that variations in force scale would have an impact on the operational effectiveness of that force and the energy costs associated with its employment such that increases in scale would increase both operational effectiveness and operational energy use.

c. Experimental Hypothesis Three

Question three asked: "What is the USMC Operational Energy trajectory with regards to the tradespace between effectiveness, energy, and other measures as defined by USMC doctrine from the Expeditionary Energy Office?" The line of inquiry sought to examine present and future force composition in similar operational contexts and analytically determine the trajectory toward or away from the centroid of the (fast, austere, lethal) spectrum. The team had no specific hypothesis about the USMC trajectory in this regard, but did make an assessment of an engineering and experimental Course of Action (COA) necessary to pursue the question. The team determined early in the project that in order to address the question of trajectory each data point in that trajectory represented a unique SE problem. Therefore, it would be necessary to perform the entire SE process, modeling, design of experiments, and perform tradespace analysis at each data point to infer the trajectory. The team elected not to pursue additional trajectory data points due to time constraints.

2. Experimental Planning

a. Define Goals

Goals of the experimentation process were bounded by the capability and fidelity present in the MANA representation. MANA is a low resolution representation of the employed system specified by the SE team. Additionally, a good deal of functionality specified by the SE team was not achieved in the modeling due to time constraints. Modeling gaps in functionality are defined in Table 20. Consequently, the team considered realistic goals for the experimentation process to include the following.

- Goal 1: Obtain stable frequency statistics from experiments. The investigation of replication requirements are discussed in Chapter IV.E.1.b.
- Goal 2: Determine the impact of random variable inputs on the outputs of the MANA models.
- Goal 3: Demonstrate scale in the configuration of the experiments to expose energy and effectiveness relationships to scale.
- Goal 4: Generate adequate data points to distinguish a threshold of mission success from energy and effectiveness metrics.

b. Identify Dependent and Independent Variables

In terms of the experimentation process, dependent variables consist of all MANA output metrics defined in Table 23. Independent variables consist of all the MANA input properties which the team considered appropriate for determining output. The base model design is representative of the system form and function and is traceable to architecture specified in Chapter III. Input properties schema definitions are provided in Chapter IV.C.1 and specifics regarding agent properties input settings are discussed in Chapter IV.D.5. Dependent and independent variables are summarized below.

1. Dependent Variables: Defined in Table 23.
2. Independent Variables

- Random Variables: Weapon Accuracy, Random Patrol, Personal Concealment, Agent Personality
- Blue Squad Activity Map Prescription
- Number of Blue Agents
- Type of Blue Agents
- Weapons Allocation to Blue Agents
- Fixed Red Agent and Weapons Configuration (Quantity, Type and Activity Map)

c. Choose Probability Model

The stochastic elements of the experimentation were limited according to features that MANA supported. Additionally, advanced modeling properties, which were required to extend the model resolution through incorporation of additional random properties, were not implemented in the models. Random variables associated with the inputs are as follows.

> <u>Weapon Accuracy (Blue & Red Forces):</u> Weapon accuracy was specified as a function of range such that a specified percentage of target hits would occur depending on the range from the weapon to the target. Interpolation was selected to cause MANA to represent intervals between the three ranges specified. This translates into a probability of hit at each range. The weapons accuracy random variable was believed to have a significant impact on the MANA output fires and casualty metrics.
>
> <u>Random Patrol (Blue Aircraft & Red troops):</u> Random patrol allowed the specification of random variation in the prescribed activity path that agents follow toward waypoints and objective areas using an exponential distribution. This introduced variability into the total patrol path length and therefore impacted the fuel use for aircraft, although modestly. Random patrol of aircraft was not seen as a major contributor to stochastic behavior in the model. Red ground agents were given random patrol attributes within a tightly confined enemy compound area. This was expected to have an impact on metrics related to the battle engagement since discovery of red agents would be based on random intervals as the red agents move through the terrain map.
>
> <u>Personal Concealment:</u> Personal concealment added a random attribute to ground troops to reduce detection based on the agents camouflage. The details of this distribution were not available in the MANA manual, but a percentage factor was provided that is believed to be the degree to which agents blend in with surroundings. This factor was not believed to be a major contributor to outcomes in the battle based on the setting used in the models.
>
> <u>Agent Personality:</u> Agent personality is determined through the selection of propensity settings for five objectives. A value between -100 and +100 establishes a bias that the MANA software used to cause agent movement toward or away from the object. The team believed the propensity settings to significantly weigh on all effectiveness metrics associated with the autonomous battle activity. The five propensity objectives include enemy, friends, neutrals, waypoints, and terrain.

The use of scale led to the idea of hypothesis testing on select MANA output metrics across the three scale levels. In particular the team was interested in gathering statistical evidence about the relative variability of the data within each design level and between each design level. The desire was to find adequate evidence that the null hypothesis should be rejected. This would lead to the conclusion that variability in the data between levels was not just a random occurrence. Furthermore, the data could then be appropriately used to draw further conclusions about the tradespace (Geoffrey and Steiner 2003).

$$H0: \ All\ \mu\ are\ equal$$
$$H1: Not\ all\ \mu\ are\ equal$$

d. Choose Experimental Design

The M&S team implemented three separate but similar models which demonstrated input variability based on all of the selected independent variables. The exact allocation of agents, their weapons, and CONEMP were actually constraints of the experimentation based on the requirement to demonstrate scale of the SPMAGTF. The final DOE based on scale has been specified within the agent properties, squad construct, and activity map design as referenced below.

- Random Variables: Chapter IV.D.5.
- Blue Squad Activity Map Prescription: Chapter Appendix E.
- Number and Type of Blue Agents: Table 5 and Table 6 (exceptions: no mortars, CAS, or AirLOG)
- Weapons Allocation to Blue Agents: Table 5 and Table 6 (exceptions: no mortars, CAS, or AirLOG)
- Fixed Red Agent and Weapons Configuration (Quantity, Type and Activity Map): Figure 92 and Figure 93 in Appendix E.

e. Validate Design

Validation of the three models and the experimental designs was not possible in this capstone project due to time constraints and the availability of comparable data to determine the models validity. Model validity in this respect would support a finding that the model could be used for similar experiments to draw additional conclusions. While the team believes the models constructed are value added and do support a baseline from which to extend the research, the models fall short of being valid “as is” for additional experimentation. The next step in the evolution of this line of inquiry would be to review the DOE process and propose enhancements to model fidelity and experimental input options which would support repeatability of experimentation with the “as is” models.

3. Alternative DOE Framework

The team framed, but did not execute, an alternative to the scale level DOE in an effort to better understand behavioral based aspects of the energy/effectiveness spectrum. The pursuit was driven by a desire to understand energy commitments in terms of agent propensities. In this paradigm the objective is to identify design points which adequately characterize a tradespace based on varying agent propensities across a multi-variate behavioral spectrum. Agents and groups of agents’ propensities would be set according to certain biases that define this spectrum such as survival, victory, efficient use of resources, and so forth. This methodology would allow competing values to be examined in the tradespace.

In a military context, it is noteworthy that the inquiry becomes moot when the bias is simply to follow lawful orders. In such cases agents are acting according to military doctrine. Behavioral Based Energy modeling may be a necessary component of determining warfighting doctrine in light of the Marine Corps present need to return balance to the lethality spectrum. In this light it is noteworthy that energy is not the only issue that competes for Marines decisions. The model can be extended to behavioral based Value modeling paradigm, where trades are considered on the basis of whatever is considered to be valuable. In this way analytical methods can be utilized to treat just about anything as the independent variable.

G. CHAPTER SUMMARY

An ABMS paradigm was adopted based on the desire to represent autonomous coupling to energy drivers and the need to adequately model multiple interactions in a battle space. MANA was selected as the key ABMS tool due to its military use fitment and support at NPS in large part. A model construction process established steps to control the construction of the executable model through implementation of input considerations, model design, and output considerations. Several modeling tools were adopted to support the MANA model construction and facilitate eventual metrics presentation.

Specific input considerations included the development of two Excel workbooks to support the model construction. The agent properties workbook supported the collection of agent data consistent with that specified by the SE generated physical architecture and in accordance with the MANA schema. The agent CONEMP workbook supported the organization and instantiation of agents into the proper context to support the so called lay down of the Barra map. The team implemented a CM process to control the update of these workbooks which facilitated team learning as the model construction.

Three models were designed which represent the three scale levels specified by the SE team. The model implementation did not include all of the features such as CAS, AirLOG, casualty evacuation, some C2 SA features, and indirect fires; however, each model did demonstrate the key QRF insertion energy driver with the effectiveness of an autonomous battle engagement. Model design entailed the understanding of MANA limitations, specification of high resolution background and terrain maps, detailed specification of squads and their hierarchical relationships to support transportation, agent modeling assumptions regarding fuel, armor and weapons penetration, other weapons and sensor properties, agent behavioral and personality modeling, and SA/C2 configuration. The mission sequence of the CONOP was represented through the use of activity map implementations for each squad that prescribe path following tactics associated with the convoy patrol, QRF insertion, and ultimate autonomous battle engagement. Reconciliation of the model functionality to that specified in the SE system decomposition suggested that the team was able to demonstrate limited targeting and maneuver capability as well as direct fires over three levels of scale. The gap associated with the model reconciliation was the source for a mitigation strategy to developed supplemental energy driver analysis in support of augmenting the tradespace analysis.

The team executed an experimental process that included forming hypotheses from the research questions and performing a series of steps to plan the MANA experiments. Goals of experimentation included obtaining stable statistics, relating random variable inputs to output statistics, demonstrating scale, and generating adequate data points to determine a threshold of mission success. Dependent variables were embodied in the Final MANA Metrics Table 23, and independent variables consisted of random variables, blue squad activity maps, the number, type, and weapons allocations for blue agents, and the red agent configuration. A probability model and statistical test was proposed to examine statistical significance of key MANA metrics. The final experimental design has been elaborated throughout this document and is based on the USMC SPMAGTF 1st company allocation specified by the SE team for three design points to demonstrate scale. The red force configuration remains constant throughout all simulations.

Model output considerations were implemented to acquire the appropriate MANA data using the correct experimental replications, transform it into the best set of MANA final metrics usable by the SE team, and build statistical metrics for the resulting data set. The modeling team produced fuel, fires, casualty, and battle length metrics to govern the MANA output. Reconciliation to the SE specified MOEs revealed that MANA did not provide full warfighting spectrum coverage with its output metrics, but did support the fires and casualty effectiveness data. Standard descriptive statistics were specified along with a prescription to perform ANOVA on output metrics.

THIS PAGE INTENTIONALLY LEFT BLANK

V. ANALYSIS OF ALTERNATIVES

A. INTRODUCTION

The Analysis of Alternatives (AoA) was limited to some extent by the accomplishments of the experimentation process. The team recognized that a gap existed between the MANA modeling effort and the engineering specification of form, function, and measures and documented this gap in Table 20. Chapter IV.D.7 (MCT task reconciliation) analyzed the gap and provided insight into what was and was not accomplished in the MANA modeling. Metrics were further determined from the MANA accomplishments, but they did not fully support all of the SE prescribed system measures necessary to evaluate functionality implemented in the CONOP. Table 24 summarized a reconciliation of the MANA metrics to the SE MOEs established in III.C. Final MANA metrics (Table 23) were expected by the modeling team to constitute the full and final set of available metrics from which data would emerge to support tradespace analysis. As it turned out, the review of the data corroborated the need for separate energy link analysis. Additionally, results by analysis was suggested as another means to elaborate MOE data. It was clear that another step was needed to state final MOEs based on review of MANA metrics, further analysis, and incorporation of energy link analysis. Once stated, the final MOEs provided the team with the basis for the AoA.

The AoA chapter includes a discussion required to frame the construction of the tradespace. The question of mission success is examined in light of available data. Research questions are reviewed, and stated in terms of what tradespace data is needed to answer the questions. The objective tradespace construction methodology presents methods that the team deemed ideal given full experimental data. The actual methods are discussed in terms of the use of analytical means to augment the experimental results.

The statement of final MOEs and MANA metrics traceability provide the basis for further elaboration of the AoA. The energy analysis provides a holistic review of all energy drivers associated with all ACE and GCE components in each link of the CONOP and concludes with the bottom line numbers for the fuel cost associated with each scale model represented in MANA. MANA experimental results were presented, statistics reviewed, experimentation goals revisited, and summary combined energy and effectiveness results stated. The combined results provided the key data necessary to evaluate trades associated with the experimental results. Four key elements of the tradespace were analyzed, including battle loss exchange, hit rate efficiency, injury rates, and battle length. Finally, the full MOE results were tabulated, rolled up into a composite tradespace and conclusions stated.

B. AOA FRAMEWORK

The engineering process steps elaborated in Chapter II enabled the team to frame the tradespace in terms of the research questions and to develop a tradespace construction methodology. Specifically, development of system function, form, and metrics all of which are traceable back to the stakeholder's original need formed the basis for the tradespace framework. Objectively, the engineering team created a vision that would guide organization of the experimental results pursuant to answering the research questions. Realistically, the team accepted the limited results of the MANA experiments and determined to address the tradespace in terms of the war fighting dimension supported by the results and supplemental analysis.

1. Mission Success

The team established the definition of the successful Barra mission execution in Chapter III. Success required all critical MOE thresholds to be met and at least 50% of non-critical MOEs to be met. The criterion was predicated on the ability to fully model the form and function of the notional system in its operational context. Since some of the functionality was not modeled, the success determination also depended on results by analysis. Chapter IV.D.7 reviewed the compliance levels of the MANA model to the SE specification and concluded that modeling demonstrated limited targeting and maneuver capability as well as direct fires. The recommended supplemental energy analysis provided additional inputs by analysis. Furthermore, review of the CONOP and harvested MANA simulation data provided additional input for results by analysis. Based on this reality, the team decided that the definition proposed in the SE execution was appropriate and that the determination of a successful mission execution could still be made through use of the following methods.

- <u>Experimental Results</u>: MANA experiments provided a set of final MANA metrics which allowed the construction of certain measures useful for analytical purposes and for traceability to the SE established MOEs.
- <u>Results by Analysis:</u> Analytical methods were used to determine results from a combination of harvested MANA data not in the Final MANA Metrics list, assumptions present in the CONOP, and the supplemental energy link analysis.

2. Framing the Tradespace from the Research Questions

a. Question 1: Threshold Success

The first research question was concerned with the threshold cost of mission success. A determination of threshold success supports the evaluation of energy efficient force application in the battle space. The engineering team specified three SPMAGTF design points for the tradespace examination, any one of which may satisfy a criteria of success, but none of which are likely to exactly match the threshold level. The team expected that a threshold success point could be inferred analytically from interpolation of an efficient frontier represented in the tradespace.

> What is the energy cost associated with the execution of a successful USMC expeditionary mission, where the measures of success are determined by Operational Effectiveness?

b. Question2: Dynamic MEB Scaling

The team did not pursue dynamic MEB scaling; however, the SPMAGTF force level definitions were sufficient to allow collection of multiple data points to demonstrate scale and its impact to energy and effectiveness. The representative tradespace is envisioned as a set of data points obtained from the measures data associated with the six warfighting functions at each of these levels of scale.

> What are the impacts of variations in the dynamic MEB scaling on Operational Effectiveness and Operational Energy?

c. Question 3: Operational Energy Trajectory

Chapter IV.F.1.c provided a COA for the pursuit of this research question. Although the team did not have time to pursue this objective some consideration was given to what the tradespace might look like. The tradespace expectation is that this effort would result in cost/benefit trades similar to question 2, but each for a different capability set. In constructing this space, the trajectory in time would be exposed showing strategic options available for consideration to steer the actual capability evolution toward desired objectives.

> What is the USMC Operational Energy trajectory with regards to the tradespace between effectiveness, energy, and other measures as defined by USMC doctrine from the Expeditionary Energy Office?

3. Tradespace Construction Methodology

a. Objective Tradespace Construction

The team considered the objective trade study to include modeling and experimentation that supported all function, form, and operational context specified in the SE process. Ideally, all executable models would be developed with enough fidelity to support experimental collection of metrics that supported all MOEs define by the SE team. The experimentation would then produce a useful predictor of mission success which was measurable in all six dimensions of the war fighting spectrum. The process for constructing the resulting tradespace would entail the weighting and rollup of measures from each functional area into warfighting OMOEs, each of which could be plotted on a common tradespace chart against energy. The evolving picture is an operational energy vs. operation effectiveness chart with full dimension based on experimental results.

b. Realistic Tradespace Construction

In lieu of full experimental results the team determined that the combination of experimental data combined with availability of data by analytical means could still be utilized to infer the full tradespace. The team answered the experimental gap regarding energy modeling through the supplemental energy link analysis. Results by analysis are not considered as conclusive as results through experimentation for several reasons. First, in cases where MANA harvest data is not used, analysis does not incorporate the agent based behavior that MANA offered in the ground based battle. Second, analysis performed in this regard did not incorporate stochastic properties which might be necessary to effectively represent a realistic scenario. Finally, there is not a high degree of separation between the three scale levels MOE values based on subjective assessments necessary in the analysis. This was a key contributor to the moderation of the impact of MOEs by analysis versus MOEs by experimentation as demonstrated in Chapter V.E.3.a.

c. Restatement of MOEs and MANA Metrics Traceability

The MOEs for the tradespace analysis were restated in the MOE traceability matrix, Table 25. This table defines the measures which were used to construct the final tradespace and make a determination of mission success. The table contains a total of 22 MOEs determined through analysis and one MOE by experimentation. The Experimentation MOE is linked directly to final MANA metrics as shown in the MANA traceability matrix, Table 26. The final MANA metrics table also shows constructed metrics traceability within the MANA output data.

Table 25. Restated MOEs Traceability Matrix (after United States Marine Corps 2014)

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
MCT 1.3.4.1.1 Conduct Airborne Rapid Insertion/Extraction										
M8	Time	To provide extraction operation.	30 min / 25 min	N	Analysis	materiel / non-materiel factors, operationally effective	OER Maneuver MCDP 1–0	MCT 1 Deploy Forces / Conduct Maneuver	MCT1.3 Conduct Maneuver & Close Forces	MCT1.3.4 Conduct Assault Support Operations
MCT 1.6.5.11 Conduct Quick Reaction Force Operations										
M1	Percent	Force required for Quick Reaction Force operations.	100% / 75%	N	Analysis	materiel / non-materiel factors, operationally effective	OER Maneuver MCDP 1–0	MCT 1 Deploy Forces / Conduct Maneuver	MCT 1.6 Dominate the Area of Operations	MCT 1.6.5 Conduct Tactical Operations
M2	Time	Quick Reaction Force reaction time.	15 min / 15 min	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Maneuver MCDP 1–0	MCT 1 Deploy Forces / Conduct Maneuver	MCT 1.6 Dominate the Area of Operations	MCT 1.6.5 Conduct Tactical Operations
MCT 1.6.11.3 Conduct Screen Operations										

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
M3	Percent	Of enemy troops detected before they could come into contact with friendly flanks or rear areas.	90% / 100%	N	Analysis	materiel / non-materiel factors, operationally effective	OER Maneuver MCDP 1–0	MCT 1 Deploy Forces / Conduct Maneuver	MCT 1.6 Dominate the Area of Operations	MCT 1.6.11 Conduct Armored Security Ops
M4	Percent	Of enemy troops detected which were engaged by fire support or maneuver assets before they could come into contact with friendly flanks or rear areas.	95% / 100%	N	Analysis	materiel / non-materiel factors, operationally effective	OER Maneuver MCDP 1–0	MCT 1 Deploy Forces / Conduct Maneuver	MCT 1.6 Dominate the Area of Operations	MCT 1.6.11 Conduct Armored Security Ops
MCT 2.1.1.5 Support Targeting										
M1	Y/N	Targets assigned relative value.	N / Y	N	Analysis	materiel / non-materiel factors, operationally effective	OER Intelligence MCDP 1–0	MCT 2 Develop Intelligence	MCT 2.1 Plan and Direct Intelligence Operations	MCT 2.1.1 Conduct Intelligence Functions
M3	Percent	Of targets available for striking.	75% / 100%	N	Analysis	materiel / non-materiel factors, operationally effective	OER Intelligence MCDP 1–0	MCT 2 Develop Intelligence	MCT 2.1 Plan and Direct Intelligence Operations	MCT 2.1.1 Conduct Intelligence Functions

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
M9	Y/N	Maintain display of current enemy situation with target locations and priorities.	N / Y	N	Analysis	materiel / non-materiel factors, operationally effective	OER Intelligence MCDP 1–0	MCT 2 Develop Intelligence	MCT 2.1 Plan and Direct Intelligence Operations	MCT 2.1.1 Conduct Intelligence Functions
M14	Incidents	Of Blue-on-Blue engagements.	3 / 0	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Intelligence MCDP 1–0	MCT 2 Develop Intelligence	MCT 2.1 Plan and Direct Intelligence Operations	MCT 2.1.1 Conduct Intelligence Functions
MCT 2.1.1.6 Support Combat Assessment										
M5	Y/N	Intelligence capable of being acquired to support Assessment (e.g., COMCAM, Imagery, SIGINT, HUMINT, CA, etc.).	N / Y	N	Analysis	materiel / non-materiel factors, operationally effective	OER Intelligence MCDP 1–0	MCT 2 Develop Intelligence	MCT 2.1 Plan and Direct Intelligence Operations	MCT 2.1.1 Conduct Intelligence Functions
MCT 3.2.3.1.1 Conduct Close Air Support (CAS)										
M4	Number	Of sorties daily sustained during contingency/combat operations.	1 / 2	N	Analysis	materiel / non-materiel factors, operationally effective	OER Fires MCDP 1–0	MCT 3 Employ Firepower	MCT 3.2 Attack Targets	MCT 3.2.3 Conduct Aviation Delivered Fires
MCT 3.2.4.1 Conduct Direct Fires										

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
M1	Percent	Of targets attacked with desired effects.	16% / 46%	Y	Experimental	materiel / non-materiel factors, operationally effective	OER Fires MCDP 1–0	MCT 3 Employ Firepower	MCT 3.2 Attack Targets	MCT 3.2.4 Conduct Ground Delivered Fires
M5	Y/N	Take the enemy under fire using lethal and nonlethal gunfire delivered on target.	N / Y	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Fires MCDP 1–0	MCT 3 Employ Firepower	MCT 3.2 Attack Targets	MCT 3.2.4 Conduct Ground Delivered Fires
M6	Number	Of missions completed.	1 / 2	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Fires MCDP 1–0	MCT 3 Employ Firepower	MCT 3.2 Attack Targets	MCT 3.2.4 Conduct Ground Delivered Fires
MCT 4.3.8 Conduct Air Logistic Support										
M5	Number	Of sorties daily sustained during contingency/combat operations.	0 / 1	N	Analysis	materiel / non-materiel factors, operationally effective	OER Logistics MCDP 1–0	MCT 4 Perform Logistics and Combat Service Support	MCT 4.3 Conduct Transport Services	MCT 4.3.8 Conduct Air Logistics Support

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
M8	Percent	Of required support material distributed at the time and place required.	90% / 100%	N	Analysis	materiel / non-materiel factors, operationally effective	OER Logistics MCDP 1–0	MCT 4 Perform Logistics and Combat Service Support	MCT 4.3 Conduct Transport Services	MCT 4.3.8 Conduct Air Logistics Support
MCT 4.5.5 Conduct Casualty Evacuation										
M6	Hours	From wound or injury until person is in surgery or other appropriate care.	2 / 1	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Logistics MCDP 1–0	MCT 4 Perform Logistics and Combat Service Support	MCT 4.5 Provide Health Services	MCT 4.5.5 Conduct Casualty Evacuation
MCT 5.3.1.2 Exercise Tactical Command and Control										
M3	Percent	Of units responding appropriately to orders.	95% / 100%	N	Analysis	materiel / non-materiel factors, operationally effective	OER Command & Control MCDP 1–0	MCT 5 Exercise Command and Control	MCT 5.3 Direct, Lead, Coordinate Forces / Operations	MCT 5.3.1 Direct Operations
MCT 5.3.4.4 Coordinate Ground Surface Fires										

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
M1	Number	Of targets successfully engaged.	90% / 100%	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Command & Control MCDP 1–0	MCT 5 Exercise Command and Control	MCT 5.3 Direct, Lead, Coordinate Forces / Operations	MCT 5.3.4 Conduct Fire Support Coordination
MCT 5.3.4.5 Coordinate Close Air Support (CAS)										
M8	Minutes	Of on-station time of CAS support.	60 min / 30 min	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Command & Control MCDP 1–0	MCT 4 Perform Logistics and Combat Service Support	MCT 5.3 Direct, Lead, Coordinate Forces / Operations	MCT 5.3.4 Conduct Fire Support Coordination
MCT 6.1.1.5.3 Conduct Patrolling										
M1	Incidents	Of friendly operations degraded due to enemy observation, detection, interference, espionage, terrorism and/or sabotage.	1 / 0	N	Analysis	materiel / non-materiel factors, operationally effective	OER Force Protection MCDP 1–0	MCT 6 Protect the Force	MCT 6.1 Provide Security	MCT 6.1.1 Conduct Active Security
M2	Incidents	By enemy troops, or partisans, affecting security of force and means in the operations area.	1 / 0	N	Analysis	materiel / non-materiel factors, operationally effective	OER Force Protection MCDP 1–0	MCT 6 Protect the Force	MCT 6.1 Provide Security	MCT 6.1.1 Conduct Active Security

MOE	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Method	Effective Need	Requirement	MCT-level 1	MCT- level 2	MCT- level 3
M9	Y/N	Urban patrolling conducted.	N / Y	Y	Analysis	materiel / non-materiel factors, operationally effective	OER Force Protection MCDP 1–0	MCT 6 Protect the Force	MCT 6.1 Provide Security	MCT 6.1.1 Conduct Active Security

Table 26. Final MANA Metrics Traceability Matrix

Metric	Units	Metric Number	Use	Traces To
HMMWV 1 Fuel Consumed	L	X1	Not used	N/A
HMMWV 2 Fuel Consumed	L	X2	Not used	N/A
HMMWV 3 Fuel Consumed	L	X3	Not used	N/A
HMMWV 4 Fuel Consumed	L	X4	Not used	N/A
CH-53K 1 Fuel Consumed	L	X5	Not used	N/A
CH-53K 2 Fuel Consumed	L	X6	Not used	N/A
MV-22 Fuel Consumed	L	X7	Not used	N/A
Blue Injured	Qty.	X8	Construction	X22, X25
Blue Dead	Qty.	X9	Construction	X21, X22
Blue Active	Qty.	X10	Construction	X21, X22, X25
Blue Total Hits	Qty.	X11	Construction	X24
Red Injured	Qty.	X12	Construction	X22
Red Dead	Qty.	X13	Analytics	X21, X22
Red Active	Qty.	X14	Construction	X21, X22
Red Total Hits	Qty.	X15	Construction	X23
Blue Ammo Used	Qty.	X16	Construction	X23
Red Ammo Used	Qty.	X17	Construction	X24
Blue Fratricide	Qty.	X18	Zero all cases	
Red Fratricide	Qty.	X19	Not used	N/A
Battle Length	sec	X20	Analytics	
Loss Exchange Ratio (Casualty)	%	X21	Analytics	MCT3.2.4.1-M1
Loss Exchange Ratio (Casualty and Injured)	%	X22	Analytics	
Blue Fires Efficiency	%	X23	Analytics	MCT3.2.4.1-M1
Red Fires Efficiency	%	X24	Analytics	
Blue Injury Rate	%	X25	Analytics	MCT3.2.4.1-M1

d. Tradespace Results Hierarchy

A tradespace results hierarchy was built (Figure 47) to further articulate the relationship between experimental results, results by analysis, and the successful mission determination. The successful mission determination was accomplished by examining results obtained from the MANA experiments direct fires mission, performing energy link analysis, and examining other MOEs in light of the CONOP assumptions built into the modeling. Additional insight was gained through examination of specific MANA metrics shown on the right side of the figure. Traceability to specific MANA metrics is shown in Figure 47 for each applicable results hierarchy element. Chapter V.E provides detailed analysis for the elements in the tradespace hierarchy.

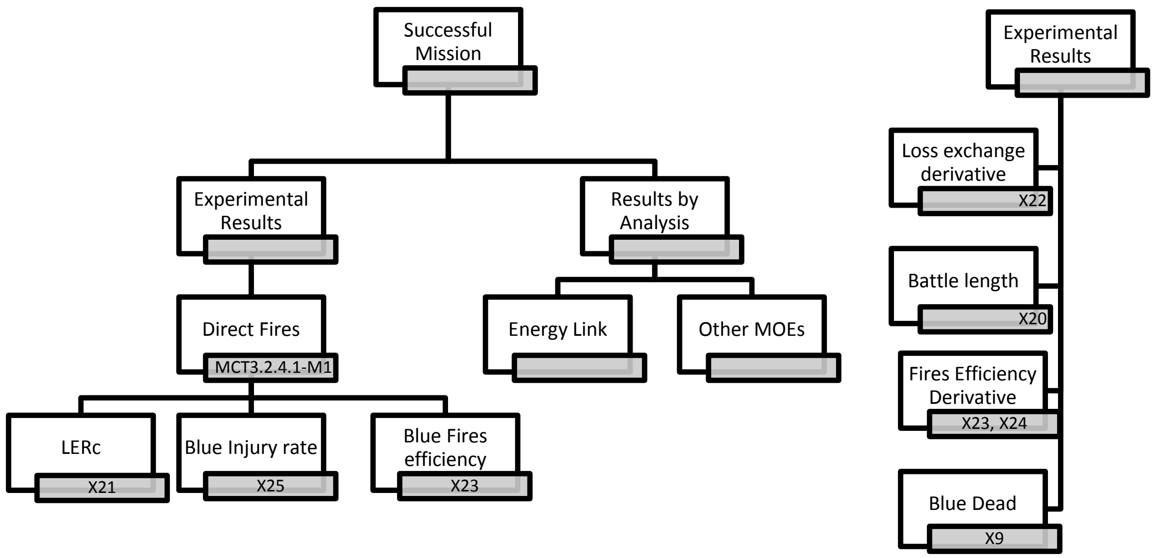


Figure 47. Tradespace Results Hierarchy

C. MISSION ENERGY LINK ANALYSIS

1. Introduction

The mission energy link analysis served to capture all of the fuel consumption data that was not accounted for during the MANA model simulations for the 3-Platoon, 4-Platoon, and 5-Platoon configurations. While the MANA model served to analyze the variations in configuration from an effectiveness perspective, this fuel consumption analysis investigated the various components of each configuration and their contribution to the overall fuel consumption total for the mission.

Each fuel consumer of the SPMAGTF was identified and separated into its parent component – ACE or GCE. After the initial classification of elements between aviation and ground components, the individual elements were grouped by their contribution to the mission – e.g., the AH-1Z attack helicopter served as CAS for the mission (NAVAIR 2012) while the MV-22B (United States Marine Corps 2014) and CH-53K (United States Marine Corps 2014) served as the primary means for QRF insertion. After each element was identified by role and mission type they were grouped, as appropriate, into the individual sorties required to complete the mission.

After the completion of the modeling portion, the results for each platoon size were analyzed and compared in terms of the following four parameters.

1. Fixed fuel consumption

Fixed fuel consumption was defined as liters of fuel consumed per asset/sortie/mission/platoon configuration.

2. Variable fuel consumption

Variable fuel consumption was defined as liters of fuel consumed during engagement and MEDEVAC scenarios per asset/sortie/mission/platoon configuration.

3. Engagement length

Engagement length was determined experimentally through the MANA simulations for each scale model.

4. Number of aviation assets required to complete the mission

Number of aviation assets required to complete the mission was based on the QRF size, and the injured and dead blue agents determined experimentally through the MANA simulations for each scale model.

2. MANA Connection to Energy Link Analysis

The following list details dependencies of the energy link analysis to MANA simulation output.

1. Simulation length

The simulation length was obtained from the MANA outputs and used to guide the length of time assets would be in the air and the spacing required between drop off of the QRF, activation of the MEDEVAC assets (both ACE and GCE), duration of CAS loiter/hover states, and finally pickup of QRF assets.

2. Blue Agents Injured

The number of blue agents injured was obtained from the MANA outputs and used to calculate the number of ACEs required that were to conduct MEDEVAC missions given the ACE loiter configuration capacity.

3. Blue Agents Dead

The number of blue agents dead was obtained from the MANA outputs and used to calculate the number of ACEs required that were to conduct MEDEVAC missions given the ACE loiter configuration capacity.

3. Assumptions (for all models)

In order to constrain the analysis to the low resolution level consistent with MANA's abilities and the scope of the overall project, certain assumptions were made in the creation and execution of the Excel based fuel calculations. The following assumptions remained consistent throughout each of the configurations in order to provide a fixed point of reference for each platoon size.

a. Loiter / Hover State of Aircraft

Since fuel consumption rates during loiter/hover states can vary drastically depending on many variables (Raymer 2003), and considering the team had no frame of reference to begin such calculations, the team decided to use the fuel consumption rates obtained from MPEM for an asset at average cruise speed. The primary asset affected by this decision was the AH-1Z in its role as the CAS asset, as over 70% of its total fuel consumption was during a loiter/hover state.

b. Fuel Consumption during load/unload

Given the knowledge that fuel consumption of an aircraft that is idling on the ground is less than that of an aircraft that is flying or taking off, this value was calculated at an arbitrary value of 10% of the cruise fuel consumption rate that was used during transit.

c. Simulation length

Simulation lengths for Excel based calculations were obtained from each of the three MANA model simulations. After the values were extracted an average was obtained for each platoon configuration and that value was rounded to the nearest minute. The value was rounded in order to provide a consistent basis on which to calculate average fuel consumption rates per minute.

d. Injured/Casualty Status

In order to determine the number of ACEs necessary to perform MEDEVAC missions the team utilized injured and dead statistics from the MANA simulation and then totaled them per platoon configuration. These totals were then compared to the MV-22 and CH-53K loiter configurations in order to determine the most efficient means of evacuating the injured and dead blue agents. In lieu of any actual data surrounding ambulatory to non-ambulatory ratios in injured Marines during engagements, the team decided to assume all injured agents were non-ambulatory (i.e., not able to walk/sit and therefore requiring a stretcher for evacuation). While it is obvious that this ratio of 100% non-ambulatory patients is not always correct, it does provide a worse-case scenario and an upper bound for number of ACEs required. The team did not expect the MEDEVAC operations' fuel consumption to exceed the numbers observed.

e. Time to EVAC injured/dead

In order to remain consistent with the low resolution modeling completed in this study, an extensive analysis of MEDEVAC load and transit times was not conducted. As such, engineering judgment was utilized to select the times required to load casualties onboard the ACEs.

f. GCE Ambulance HMMWV Role

In order to remain consistent with the injury/casualty status assumption, it was assumed that none of the injured would be evacuated using the ambulance HMMWV. It was assumed that the closest medical facilities capable of treating the wounded were on the sea based asset off-shore.

g. GCE HMMWV Idle Fuel Consumption Rate

Without knowing the exact configuration of the ambulance/patrol HMMWVs it was assumed that the idle fuel consumption rate was 10% of the fuel consumption during transit. Considering the total GCE fuel consumption during each of the missions was less than 1% of the total, this assumption does not have any significant bearing on the results of this scenario.

While the assumptions listed may prove to constitute a significant portion of the fuel consumption totals for certain assets, the consistency between platoon configurations allows for analysis on a higher level. By keeping the assumptions consistent throughout each platoon configuration, the team was able to draw conclusions, not based on exact numbers, but on economies of scale.

h. Baseline Configuration Data

The Excel-based fuel calculations consisted of the ACE/GCE elements required to complete the mission given a 3-Platoon, 4-Platoon, or 5-Platoon Configuration. Table 27 lists all assets required to complete the Excel-based modeling. The table contents were used as the governing set of data for each SPMAGTF configuration. The table identifies the base fuel consumption values and fuel tank size for each asset as well as a short description of the asset function and initial and ending locations.

Table 27. 3-Platoon Asset Description

Base Asset Description					
Asset	**Function**	**Fuel Consumption (L/H)**	**Fuel Capacity (L)**	**Initial Location**	**End Location**
HHMWV – M997A2 (Ambulance 4-litter, Armored)	Provides Medical services to Marines. For purpose of simulation we assume no Marines are evacuated using HMMWV. Medics only provide basic first-aid	16.3	95	Barra - OPS	Barra - OPS
HHMWV – M1165A1B3	Provides transportation for platoon patrol/screen operation throughout Barra	22.0	95	Barra - OPS	Barra - OPS
CH-53K	Main transport aircraft for QRF for all aspects of mission including insertion, MEDEVAC responsibilities, and troop withdrawal	2661.1	4698	SBAs (13.720122, -16.948440)	SBAs (13.720122, -16.948440)
AH-1Z	Provides CAS for all aspects of mission including insertion, cover during engagement, clean up and logistics resupply following the mission	908.5	1561	SBAs (13.720122, -16.948440)	SBAs (13.720122, -16.948440)
MV-22B	Provides main platform for Logistics resupply mission from SBAs to Barra for deployed Marines	1669.4	6513	SBAs (13.720122, -16.948440)	SBAs (13.720122, -16.948440)

After the assets were identified the mission outline was detailed from a perspective of sorties required to complete the mission. The following sorties were identified as the baseline configuration for each SPMAGTF size.

- Sortie 1: Initial QRF Insertion / Close Air Support Insertion.
- Sortie 2: Close Air Support
- Sortie 3: MEDEVAC (covers insertion and withdrawal)

- Sortie 4: QRF Withdrawal / Close Air Support Withdrawal
- Sortie 5: Logistics Resupply
- Ground mission 1: HMMWV (M1165A1B3) Screen Operation through Barra
- Ground mission 2: HMMWV (M997A2) Ambulance First-Aid

While the details surrounding each sortie change slightly, each platoon configuration simulation followed the same 5-sortie with ground mission profile. Figure 48 outlines the combat radius of each of the ACEs used during the simulation. The combat radius represents the distance an aviation asset can travel, loiter, provide support as needed, and then return to the point of origin with an appropriate amount of "reserve fuel" remaining (NAVAIR 2012).

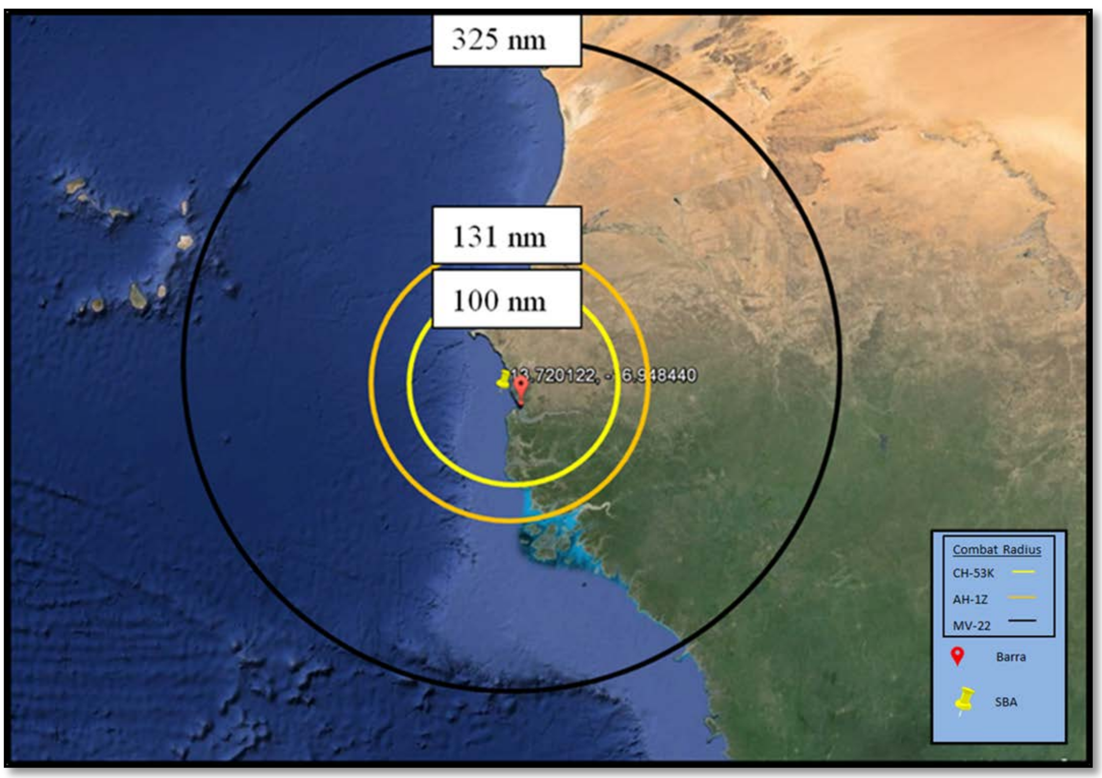


Figure 48. Combat Radius of ACEs

The yellow marker in the center represents the location of the SBAs. The red marker indicates the battle engagement area. The rings radiating from the center detail the combat radius of the individual ACEs. The black ring indicates the combat radius of the MV-22B (325 nm) (United States Marine Corps 2014), the orange ring indicates the combat radius of the AH-1Z – 131 nm (NAVAIR 2012), and the yellow ring indicates the assumed combat radius of the CH-53K – 100 nm (exact information detailing the combat radius of the CH-53K was not available. Sources indicate the CH-53K (Donaldson Company Inc 2014) to have twice (2x) the combat radius of the CH-53E – 50 nm (United States Marine Corps 2014).

After ensuring the combat radius of each ACE exceeds the requirements for the mission, the following figure was developed. Figure 49 details the starting, pickup/drop-off and ending points for the ACE and GCE during the mission.

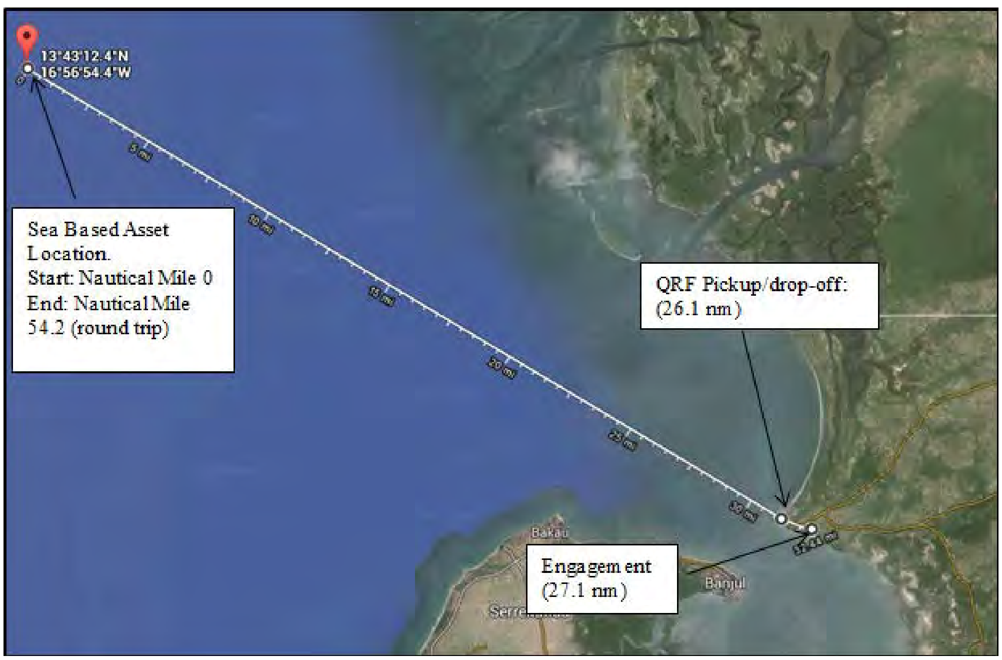


Figure 49. Aviation Combat Element Mission Route

The red marker in the upper left-hand corner indicates the location of the SBAs approximately 27 nm off-shore. As indicated, the air assets travel approximately 26.1 nm to the QRF location, pick up the QRF, and then proceed an additional nautical mile to the engagement zone. The total round trip consists of approximately 54.2 nm – less than half the combat radius of even the shortest range ACE.

In addition to the information provided, each of the configurations also shared common fuel analysis. Each mission profile exhibited characteristics of both a fixed fuel consumption value, and a variable fuel consumption value. The fixed fuel consumption value is the straight forward calculation of time-distance of travel using the equation below, and the fuel consumption per asset per minute of travel, where T = the time required for transit – measured in minutes, D = distance traveled – measured in kilometers, and R = the rate of travel – measured in kilometers/hour.

$$T = \frac{D \times 60minutes}{R}$$

The variable fuel consumption values were calculated using the average mission length value from MANA and the standard deviation of the average in order to get a picture the of the variability in fuel consumption due to engagement length.

Table 28 shows the fixed value fuel burn rates for each of the assets used throughout the three configurations under test as well as the various asset speeds used for time calculations via the equation above. The values in the table were used in calculations to determine the fuel consumption for a given ACE/GCE fuel-burn state. The two states used are the fixed consumption state and the variable consumption state. The fixed consumption state corresponds to the ACE cruise burn rate, and the GCE transit burn rate, while the variable consumption state covers ACE loiter/hover, and aircraft offload conditions, as well as GCE vehicle idle conditions.

Table 28. Asset Technical Description

Number	Asset	Max Speed (km/Hr.)	Fuel Consumption (L/Hr.)	Fuel Consumption (L/min)	Fuel Capacity (L)
1	CH-53K	315	2661.14	44.35	4697.70
2	AH-1z	274	908.499	15.14	1561
3	MV-22B	518	1669.4	27.82	6513
4	HMMWV – M997A2	64	16.3	0.27	95
5	HMMWV – M1165A1B3	64	22	0.37	95

4. Fuel Consumption Considerations – 3-Platoon Configuration

The first configuration to be examined was the 3-Platoon Configuration. The following sections detail the initial conditions, fuel consumers, and mission timeline, as well as the analysis of the results of the data provided.

a. Initial setup and configuration

By utilizing baseline information and the outputs associated with the required MANA outputs the team was able to construct the configuration shown in Table 29 for each sortie in order for the SPMAGTF to complete the mission.

Table 29. 3-Platoon Mission Profile Description

3-Platoon Initial Configuration		
Air Mission		
Sortie Number	**Sortie Type**	**Mission Details**
1	Initial QRF Insertion:	Qty. (1) CH-53K travels from Sea-Based Asset (SBAs) to Barra to pick up QRF. The asset then proceeds to engagement to drop off QRF and finally returns to SBAs.
	Close Air Support - QRF Insertion:	Qty. (1) AH-1Z travels from SBAs to Barra to provide cover while picking up QRF. Asset then proceeds to engagement area cover QRF insertion.
2	Close Air Support (CAS)	Qty. (1) AH-1Z provides Close Air support for the duration of the engagement as well as the MEDEVAC mission in the engagement area.
3	MEDEVAC	Qty. (2) CH-53Ks travel from SBAs to engagement area for MEDEVAC and return to SBAs with injured/dead (assumed all wounded require MEDEVAC).
4	QRF Withdraw	Qty. (1) CH-53K travels from SBAs to engagement area to pick up QRF and returns them to Barra. Asset then returns to SBAs.
	Close Air Support - QRF withdraw:	Qty. (1) AH-1Z travels from engagement area to Barra to cover QRF withdrawal. Asset then proceeds to SBAs.
5	LOG Resupply Mission	Qty. (1) MV-22 travels from SBAs to Barra to resupply fuel, water, ammunition, food etc., to SPMAGTF then returns to SBAs.
Ground Mission		
Ground Mission Number	**Ground Mission**	**Mission Details**
1	HMMWV Screen Operations	Qty. (3) M1165A1 w/B3 HMMWVs travel through the streets of Barra conducting a screen operation.
2	HMMWV Ambulance Operations	Qty. (2) M997A2 HMMWV Ambulances travel from Mission - Ops area to battle engagement to provide first aid for injured soldiers. No MEDEVAC trips are made via HMMWV.

b. Mission profile

In keeping with the details in Table 29 the QRF for the 3-Platoon configuration is inserted via CH-53K to the engagement area. An AH-1Z provides CAS for the QRF insertion throughout the duration of the engagement on the ground, and even during the loading of the injured and dead Marines at the end of the engagement. An ambulance in the form of a HMMWV is also present as the battle ensues. After the fighting ends and the injured and dead Marines are evacuated to the SBAs for treatment, the QRF are withdrawn, and the Ambulance and GCE return to the Mission-Ops area.

Independent of the events on the ground, and in accordance with the guidance stated in the CONOP, a logistics resupply mission is called for to replace all of the water, food, medical supplies, ammunition and other goods that are expended during the engagement. Qty. (1) MV-22B maneuvers from the SBAs to the Barra Mission-Ops area in order to drop off supplies. The supplies are unloaded and the logistics element returns to the SBAs.

c. Fuel Consumption results

The team started the analysis by looking at high level fuel consumption charts for the 3-Platoon configuration. Figure 50 details the cumulative fuel consumption for the duration of the mission. Figure 51 provides a “by-the-minute” analysis of fuel consumption during the entire engagement. Although it is difficult to see in Figure 50, the single GCE used in the simulation does have a small contribution to the fuel consumption of about 0.44% of the total fuel consumed. The peaks in Figure 51 reaching nearly 180 liters of fuel consumed per minute indicate the times at which multiple ACEs are in the air at the same time. Starting around minutes 20 through 30, and again at minutes 65 through 75, all five of the ACEs are flying one of their previously indicated missions.

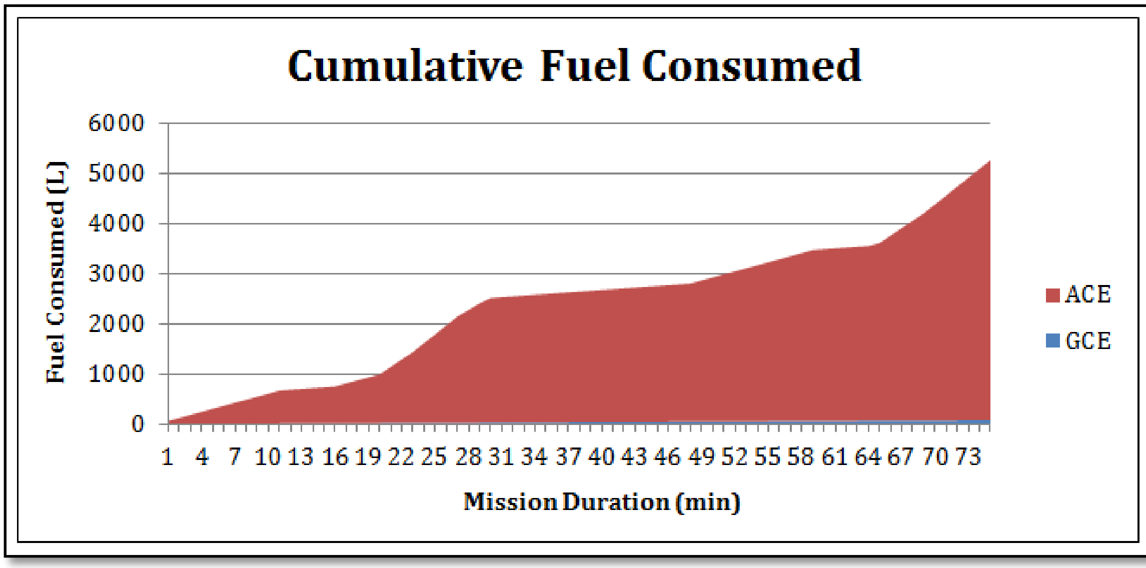


Figure 50. Cumulative Fuel Consumption – 3-Platoon Configuration

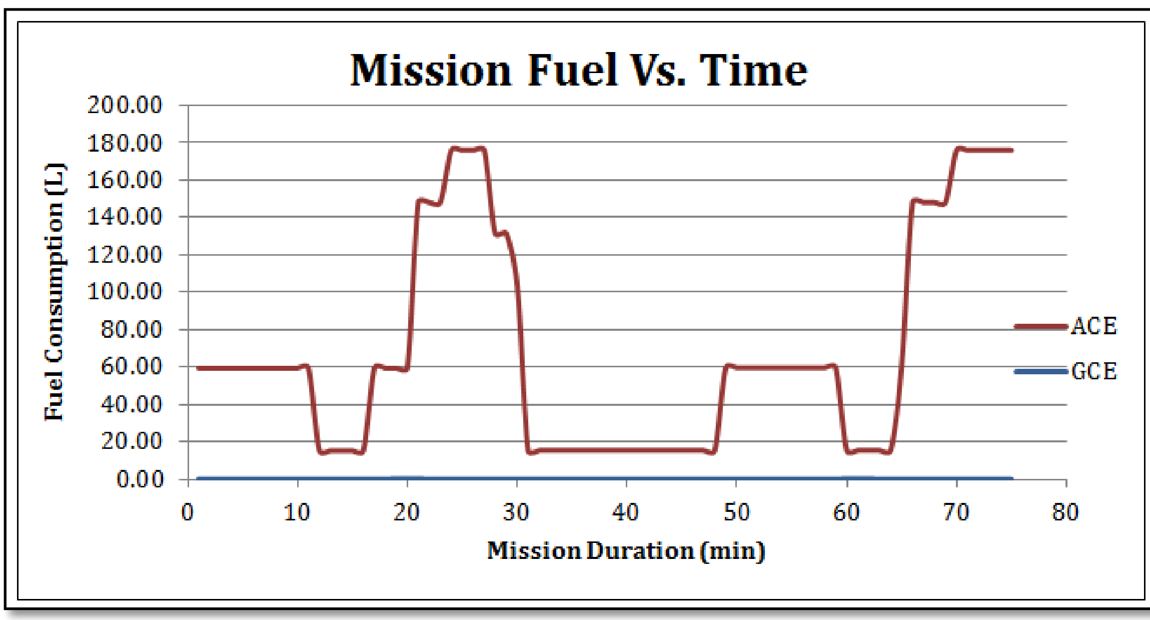


Figure 51. Mission Fuel Consumption vs. Time – 3-Platoon Configuration

Table 30 details the fixed and variable mission states as well as the fuel consumed during each state per asset. The total value for the fuel consumption per each asset state was calculated by multiplying the total time in each state by the corresponding fuel consumption value

Table 30. Total Fuel consumption per Asset – 3-Platoon Configuration

Number	Asset	Fixed Fuel Transit Time (min)	Fixed Value Fuel Consumed (L)	Variable Fuel Transit Time (min)	Variable Value Fuel Consumed (L)	Total Fuel Consumed (L)
1	CH-53K	44	1951.50	10	0.74	1952.24
2	AH-1z	22	333.12	53	802.51	1135.62
3	CH-53K	20	887.05	35	2.59	889.64
4	CH-53K	20	887.05	35	2.59	889.64
5	MV-22B	12	333.88	0	0.00	333.88
6	M997A2	6	1.63	38	1.03	2.66
7	M997A2	6	1.63	38	1.03	2.66
8	M1165A1B3	10	3.67	65	2.38	6.05
9	M1165A1B3	10	3.67	65	2.38	6.05
10	M1165A1B3	10	3.67	65	2.38	6.05
					Mission Total	5224.49

Assets one through six are listed along with the corresponding values for fixed and variable state transit times, as well as the corresponding fuel consumption value per state. The “Mission Total” of 5224.49 liters on the bottom right-hand side of the table represents the total fuel consumed by all assets in order to accomplish the mission. In order to provide an additional layer of detail, the previous values for fuel consumption can also be displayed as a function of individual sorties/ground missions. Table 31 shows the total fuel consumption per sortie and ground mission.

Table 31. Fuel Consumption per Sortie/Ground Mission – 3-Platoon Configuration

Mission Number	Description	Total Fuel Consumption
1	QRF/CAS Insertion	1142.68
2	Close Air Support	802.51
3	MEDEVAC	1779.27
4	QRF/CAS Withdrawal	1142.68
5	Logistics Resupply	333.88
6	Ground Mission	23.47
	Mission Total	5224.49

Again, the total fuel consumption for the 3-Platoon configuration remains the same – 5224.49 liters – but now the fuel distribution per sortie/ground mission can be observed. While there appears to be a somewhat even distribution of fuel consumed in missions 1, 2, and 4, it is clear that the Qty. (2) CH-53Ks that make up the MEDEVAC sortie constitute the largest fuel consumption. From a fuel consumption perspective, and a value of life perspective, minimizing the number of casualties during the engagement would minimize the number of ACEs required for MEDEVAC purposes thereby increasing Marine efficiency.

The final comparison shown in Table 32 indicates the relationship between fuel consumed and the total fuel available for each asset. As discussed in Table 27, asset technical descriptions, each asset has a fixed amount of fuel going into the simulation. In order to ensure the assets have enough fuel to complete the mission and return to base, the fuel consumption total per asset was compared to the total fuel available per asset.

Table 32. Asset Fuel Consumption vs. Fuel Availability

Number	Asset	Fuel Capacity (L)	Total Fuel Consumed (L)	20 min Reserve Required (L)	Remaining Fuel Considering Reserve (L)	Time to Bingo (min)
1	CH-53K	4697.70	1952.24	887.05	1858.41	41.9
2	AH-1z	1561.00	1135.62	302.83	122.54	8.1
3	CH-53K	4697.70	889.64	887.05	2921.01	65.9
4	CH-53K	4697.70	889.64	887.05	2921.01	65.9
5	MV-22B	6513.00	333.88	556.47	5622.65	202.1
6	M997A2	95.00	2.66	NA	92.34	342.0
7	M997A2	95.00	2.66	NA	92.34	342.0
8	M1165A1B3	95.00	6.05	NA	88.95	329.4
9	M1165A1B3	95.00	6.05	NA	88.95	329.4
10	M1165A1B3	95.00	6.05	NA	88.95	329.4

With the exception of the AH-1Z, all of the assets have more than enough fuel to complete the mission without refueling. With a burn rate of approximately 15.14 liters/minute the AH-1Z would have approximately eight more minutes of "on-station" time before it would be required to return to the SBAs for refueling.

With fuel levels coming within 8 minutes of reaching the reserve fuel level—known as "Bingo"—further scrutiny was required. Bingo is a term used by pilots to denote the point at which fuel becomes critical and return to base / ship or vector to a tanker is imperative (Crowell 2013). Upon further analysis, it was determined that if the fuel consumption rate for the AH-1Z during the loiter/hover state was off by any more than 17% or ~2.5 liters/minute, or the battle length was extended by more than 8 minutes, then the CAS asset would have had to return to base prior to completing the mission. Depending on the criticality of the CAS during the last portion of the mission, an additional CAS element would need to be called in. Assuming no other CAS elements are in the area, the minimum fuel cost for another asset to maneuver from the SBAs to the engagement area would be an additional 333.08 liters plus any additional loiter/hover fuel consumption to reach the end of the mission. While calling in an additional asset would, at a minimum, only increase the total fuel consumed by 5.9% to 5557.57 liters, it is still noteworthy given the unknown characteristics of the loiter-hover fuel consumption rate.

5. Fuel Consumption Considerations – 4-Platoon Configuration

The second configuration analyzed was the 4-Platoon Configuration. As with the 3-Platoon Configuration, the following sections provide the initial setup and configuration, mission profile, was well as the results of the fuel consumption analysis.

a. Initial Setup and Configuration

The only change in mission profile between the 3-Platoon Configuration, and the 4-Platoon Configuration was the addition of Qty. (1) MV-22B in order to transport the additional Marines that constitute the QRF. These changes have been made to sorties one and four in Table 33, but otherwise the initial profile remains the same.

Table 33. 4-Platoon Mission Profile Description

4-Platoon Initial Configuration		
Air Mission		
Sortie Number	**Sortie Type**	**Mission Details**
1	Initial QRF Insertion:	Qty. (1) CH-53K and Qty. (1) MV-22B travel from Sea-Based Asset (SBAs) to Barra to pick up QRF. The assets then proceed to engagement to drop off QRF and finally return to SBAs.
	Close Air Support - QRF Insertion:	Qty. (1) AH-1Z travels from SBAs to Barra to provide cover while picking up QRF. Asset then proceeds to engagement area cover QRF insertion.
2	Close Air Support (CAS)	Qty. (1) AH-1Z provides Close Air support for the duration of the engagement as well as the MEDEVAC mission in the engagement area.
3	MEDEVAC	Qty. (2) CH-53Ks travel from SBAs to engagement area for MEDEVAC and then return to SBAs with injured/dead (assumed all wounded require MEDEVAC).
4	QRF Withdraw	Qty. (1) CH-53K and Qty. (1) MV-22B travel from SBAs to engagement area to pick up QRF and return them to Barra. Assets then return to SBAs.
	Close Air Support - QRF withdraw:	Qty. (1) AH-1Z travels from engagement area to Barra to cover QRF withdrawal. Asset then proceeds to SBAs.
5	LOG Resupply Mission	Qty. (1) MV-22 travels from SBAs to Barra to resupply fuel, water, ammunition, food etc., to SPMAGTF then returns to SBAs.
Ground Mission		
Ground Mission Number	**Ground Mission**	**Mission Details**
1	HMMWV Screen Operations	Qty. (3) M1165A1 w/B3 HMMWVs travel through the streets of Barra conducting a screen operation.
2	HMMWV Ambulance Operations	Qty. (2) M997A2 HMMWV Ambulances travel from Mission - Ops area to battle engagement to provide first aid for injured soldiers. No MEDEVAC trips are made via HMMWV.

b. Mission profile – Variation from 3-Platoon Configuration

The only changes to the mission profile come in the form of the additional ACE required to transport the QRF to the engagement. All other details remain the same.

c. Fuel Consumption results

As with the 3-Platoon configuration, the 4-Platoon configuration yielded similar results in terms of the cumulative fuel consumption and the fuel consumption per minute figures detailed in their respective figures. As expected, the contour of the graph in Figure 52 remains almost identical when compared to the 3-Platoon configuration, but the values are higher, as there are more fuel consumers active during the simulation. Additionally, the fuel consumption versus time graph (Figure 53) shows similarity between the three and four platoon configurations. The variations exist on a scale of amplitude, not frequency. The same peaks and valleys exist in both graphs at similar time frequencies. While the peak fuel consumption rate per minute of the 3-Platoon configuration was 180 liters/minute, the fuel consumption rate per minute for the 4-Platoon configuration increases to just over 200 liters per minute.

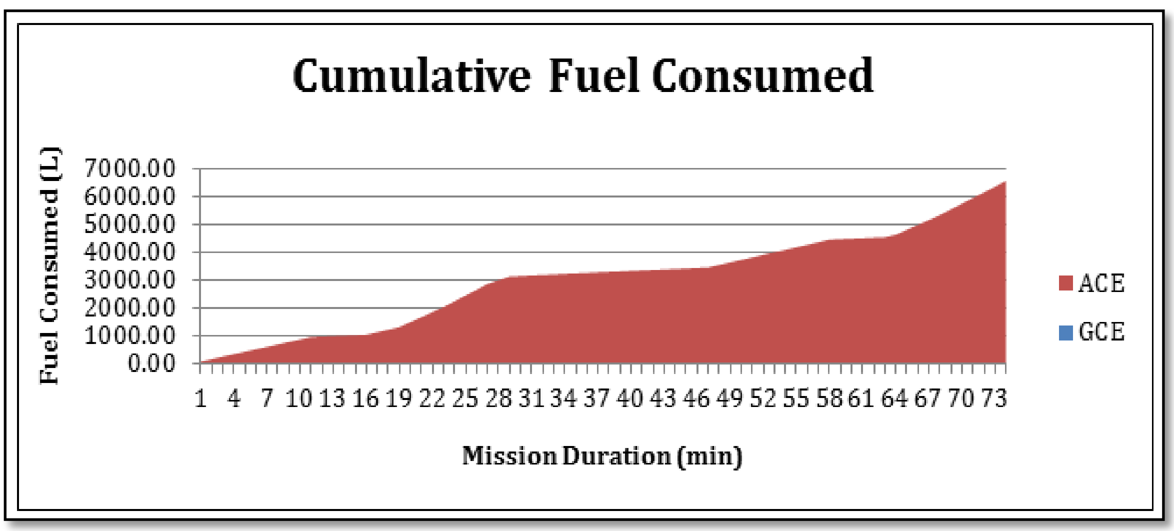


Figure 52. Cumulative Fuel Consumption – 4-Platoon Configuration

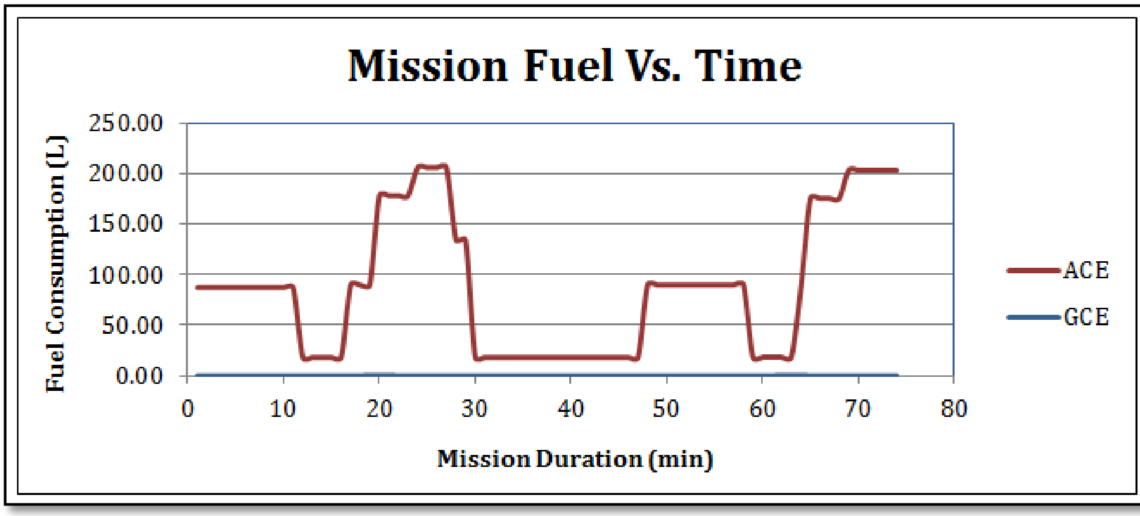


Figure 53. Mission Fuel Consumption vs. Time – 4-Platoon Configuration

Table 34 details the same fuel consumption values as with the 3-Platoon Configuration, but adds in the additional ACE asset for QRF insertion. As seen by the "Mission Total" value (6432.94 L), the increase in QRF, and therefore a corresponding increase in the ACEs required to transport the fighting force, combined with subtle variations in mission length, increased the total fuel consumption required for mission completion by nearly 23%, or 1208.45 liters.

Upon examination of the fuel consumption per sortie/ground mission data (Table 35) it is clear that sorties one and four have increased significantly as compared to the 3-Platoon configuration. As expected, the higher QRF transport requirement of the ACE increased the fuel consumption for the insertion and withdrawal missions considerably. While the fuel burn rate per minute for an MV-22B is less than half that of a CH-53K, the effects are still easy to observe.

Table 34. Total Fuel Consumption per Asset – 4-Platoon Configuration

Number	Asset	Fixed Fuel Transit Time (min)	Fixed Value Fuel consumed (L)	Variable Fuel Transit Time (L)	Variable Value Fuel Consumed (L)	Total Fuel consumed (L)
1	CH-53K	44	1951.50	10	0.74	1952.24
2	AH-1z	22	333.12	53	787.37	1120.48
3	MV-22B	44	1224.23	10	0.46	1224.69
4	CH-53K	20	887.05	35	2.59	889.64
5	CH-53K	20	887.05	35	2.59	889.64
6	MV-22B	12	333.88	0	0.00	333.88
7	M997A2	6	1.63	38	1.03	2.66
8	M997A2	6	1.63	38	1.03	2.66
9	M1165A1B3	10	3.67	65	2.38	6.05
10	M1165A1B3	10	3.67	65	2.38	6.05
11	M1165A1B3	10	3.67	65	2.38	6.05
					Mission Total	6432.94

Table 35. Fuel Consumption per Sortie/Ground mission – 4-Platoon Configuration

Mission Number	Description	Total Fuel Consumption
1	QRF/CAS Insertion	1755.02
2	Close Air Support	787.37
3	MEDEVAC	1779.27
4	QRF/CAS Withdrawal	1755.02
5	Logistics Resupply	333.88
6	Ground Mission	22.37
	Mission Total	6432.94

Availability of fuel analysis data is shown in Table 36. Consistent with the findings in the 3-Platoon Configuration, the 4-Platoon configuration shows the same vulnerability surrounding the AH-1Z and its proximity to running out of fuel before the mission is complete. While the time on station has increased by one additional minute, this only corresponds to an increase in the allowed error for the loiter-hover fuel consumption rate to just below 18%. Any more than an 18% increase in variable fuel consumption rate, or an increase in mission time will require the use of an additional CAS asset while the original asset returns to base. The cost of this asset would still be 333.08 liters, plus the cost of any additional mission time remaining.

Table 36. Asset Fuel Consumption vs. Fuel Availability

Number	Asset	Fuel Capacity (L)	Total Fuel Consumed (L)	20 min Reserve Required (L)	Remaining Fuel Considering Reserve (L)	Time To Bingo (min)
1	CH-53K	4697.70	1952.24	887.05	1858.41	41.9
2	AH-1Z	1561.00	1120.48	302.83	137.68	9.1
3	MV-22B	6513.00	1224.69	556.47	4731.84	170.1
4	CH-53K	4697.70	889.64	887.05	2921.01	65.9
5	CH-53K	4697.70	889.64	887.05	2921.01	65.9
6	MV-22B	6513.00	333.88	556.47	5622.65	202.1
7	M997A2	95.00	2.66	NA	92.34	342.0
8	M997A2	95.00	2.66	NA	92.34	342.0
9	M1165A1B3	95.00	5.68	NA	89.32	330.8
10	M1165A1B3	95.00	5.68	NA	89.32	330.8
11	M1165A1B3	95.00	5.68	NA	89.32	330.8

6. Fuel Consumption Considerations – 5-Platoon Configuration

The final configuration for the mission comparison was the 5-Platoon Configuration. The 5-Platoon configuration was analyzed as follows and, as expected represented the highest level of fuel consumption of the three options due to number of ACEs required for the mission.

a. Initial setup and configuration

The initial setup of the 5-Platoon configuration remains consistent with the 3, and 4-Platoon configurations. The differences in configuration are identified in Table 37 as an additional CH-53K utilized for QRF insertion, and an additional CH-53K utilized for the MEDEVAC mission. All other details remain unchanged between the three configurations.

Table 37. 5-Platoon Mission Profile Description

5-Platoon Initial Configuration		
Air Mission		
Sortie Number	**Sortie Type**	**Mission Details**
1	Initial QRF Insertion:	Qty. (2) CH-53K and Qty. (1) MV-22B travel from Sea-Based Asset (SBAs) to Barra to pick up QRF. The assets then proceed to engagement to drop off QRF and finally return to SBAs.
	Close Air Support - QRF Insertion:	Qty. (1) AH-1Z travels from SBAs to Barra to provide cover while picking up QRF. Asset then proceeds to engagement area cover QRF insertion.
2	Close Air Support (CAS)	Qty. (1) AH-1Z provides Close Air support for the duration of the engagement as well as the MEDEVAC mission in the engagement area.
3	MEDEVAC	Qty. (3) CH-53Ks travel from SBAs to engagement area for MEDEVAC and return to SBAs with injured/dead (assumed all wounded require MEDEVAC).
4	QRF Withdraw	Qty. (2) CH-53K and Qty. (1) MV-22B travel from SBAs to engagement area to pick up QRF and return them to Barra. Assets then return to SBAs.
	Close Air Support - QRF withdraw:	Qty. (1) AH-1Z travels from engagement area to Barra to cover QRF withdrawal. Asset then proceeds to SBAs.
5	LOG Resupply Mission	Qty. (1) MV-22 travels from SBAs to Barra to resupply fuel, water, ammunition, food etc., to SPMAGTF then returns to SBAs.
Ground Mission		
Ground Mission Number	**Ground Mission**	**Mission Details**
1	HMMWV Screen Operations	Qty. (4) M1165A1 w/B3 HMMWVs travel through the streets of Barra conducting a screen operation.
2	HMMWV Ambulance Operations	Qty. (2) M997A2 HMMWV Ambulances travel from Mission - Ops area to battle engagement to provide first aid for injured soldiers. No MEDEVAC trips are made via HMMWV.

b. Mission profile – Variation from 4-Platoon Configuration

The section above detailed the differences in configuration between the 4-Platoon, and 5-Platoon configurations, and by extension, the 3-Platoon configuration as well. All other aspects of mission profile and configuration remain unchanged.

c. Fuel Consumption results

As indicated by the results for the previous configurations, the fuel consumption profiles were expected to remain nearly identical in frequency with the major changes being in amplitude of fuel consumption. Figure 54 confirms this expectation. Through analysis ofFigure 54, it was evident that there was a significant increase in fuel consumption due to the addition of the Qty. (2) CH-53Ks required for the mission. The graph peaks at just over 9400 liters of fuel consumed during the mission. This is an increase of nearly 45% or 2880.62 liters of fuel over the 4-Platoon Configuration, and a 78% increase, or an increase of 4089.07 liters of fuel over the 3-Platoon Configuration.

As before, the overwhelming majority of the fuel consumed is through the use of ACEs. While there was a slight increase in the fuel consumed by the GCE from the 4-Platoon configuration to the 5-Platoon configuration, the GCE fuel consumption portion accounted for only 0.3% of the total fuel consumed during the model, and as such remains statistically unchanged. The Mission Fuel vs. Time graph (Figure 55) also yielded predictable results. While there are slight variations in the overall shape of the graph due to minor changes in flight departures and battle length, the vast majority of the frequencies remain unchanged. The amplitude of the graph does change, as expected. The maximum fuel consumption rate per minute for the 5-Platoon configuration peaks out at nearly 295 liters per minute.

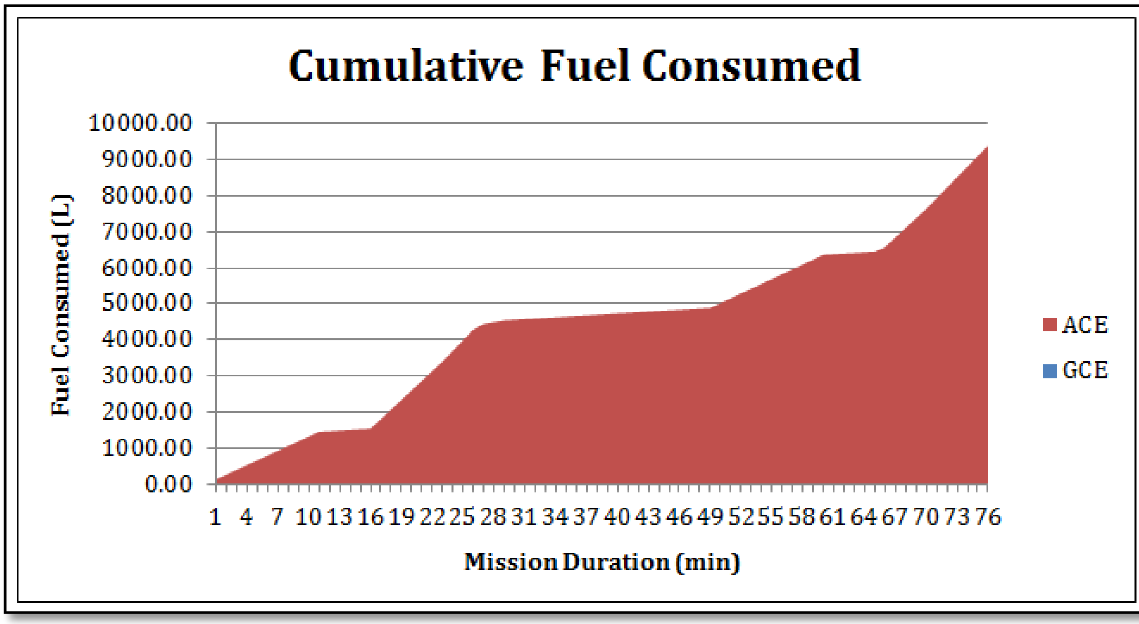


Figure 54. Cumulative Fuel Consumption – 5-Platoon Configuration

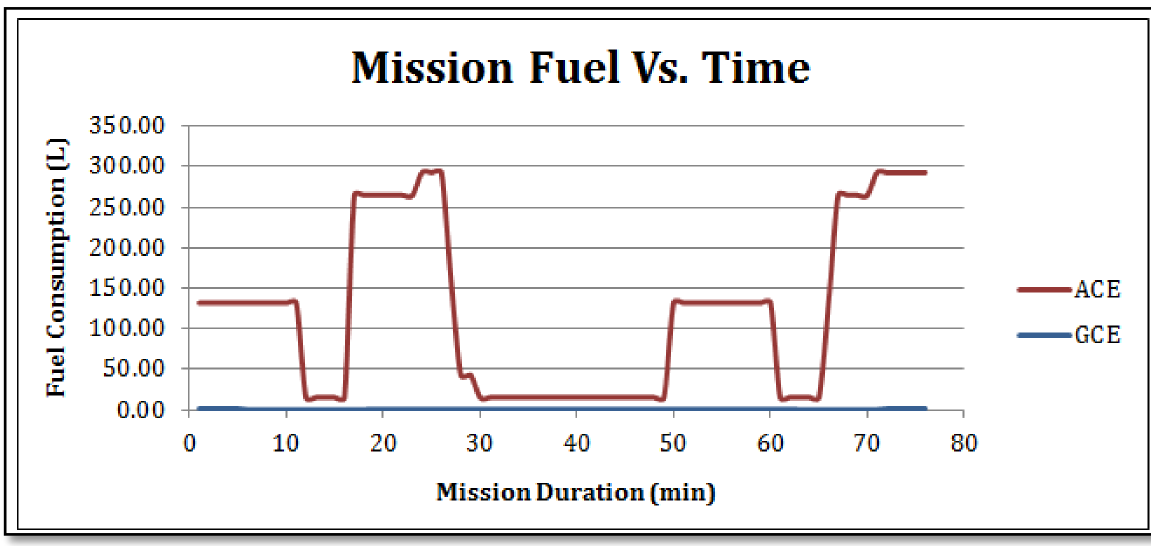


Figure 55. Mission Fuel vs. Time – 5-Platoon Configuration

In order to get an idea of the fuel consumed per asset, Table 38 was constructed. Predictably, the addition of the two CH-53Ks to the scenario had a significant effect on the total fuel consumed during the mission. Together, the two additional CH-53Ks contributed 2842.25 liters of fuel to the equation.

Table 38. Total Fuel Consumption per Asset – 5-Platoon Configuration

Number	Asset	Fixed Fuel Transit Time (min)	Fixed Value Fuel consumed (L)	Variable Fuel Transit Time (L)	Variable Value Fuel Consumed (L)	Total Fuel consumed (L)
1	CH-53K	44	1951.50	10	0.74	1952.24
2	CH-53K	44	1951.50	10	0.74	1952.24
3	AH-1Z	22	333.12	53	817.65	1150.77
4	MV-22B	44	1224.23	10	0.46	1224.69
5	CH-53K	20	887.05	35	2.96	890.01
6	CH-53K	20	887.05	35	2.96	890.01
7	CH-53K	20	887.05	35	2.96	890.01
8	MV-22B	12	333.88	0	0.00	333.88
9	M997A2	6	1.63	38	1.03	2.66
10	M997A2	6	1.63	38	1.03	2.66
11	M1165A1B3	10	3.67	66	2.42	6.10
12	M1165A1B3	10	3.67	66	2.42	6.10
13	M1165A1B3	10	3.67	66	2.42	6.10
14	M1165A1B3	10	3.67	66	2.42	6.10
					Mission Total	9313.56

Table 39. Fuel Consumption per Sortie/Ground Mission – 5-Platoon Configuration

Mission Number	Description	Total Fuel Consumption (L)
1	QRF/CAS Insertion	2731.15
2	Close Air Support	817.65
3	MEDEVAC	2670.02
4	QRF/CAS Withdrawal	2731.15
5	Logistics Resupply	333.88
6	Ground Mission	29.71
	Mission Total	9313.56

Through observation of the previous two mission configurations and comparisons with the 5-Platoon Configuration, it has been determined that the QRF size and corresponding casualties are the two main drivers for fuel consumption during the mission. By increasing the number of agents in the QRF the number of ACEs required to transport them also increases; this fact is known in advance. Counter intuitively, MANA results indicated that even with additional fire power on the ground, the "injured rate" still continued to climb. Consequently, additional assets were required for MEDEVAC purposes.

The final examination of the 5-Platoon configuration comes in the form of the Table 40. As with the previous two configurations, it was necessary to ensure that all elements in the model would meet the fuel requirements for the duration of the engagement. The ACE in need of careful consideration was the AH-1Z. For the given configuration and mission profile, the CAS asset came within seven minutes of "Bingo." A quick calculation indicated that had the fuel consumption rate for the variable state been off by more than 13%, approximately two liters/minute, or the mission length changed, the CAS asset would have been required to return to base prior to completion of the mission. The fuel cost of an additional AH-1Z for CAS given no other assets in the immediate area would be 333.08 liters, plus the cost of any additional mission time required.

Table 40. Asset Fuel Consumption vs. Fuel Availability – 5-Platoon Configuration

Number	Asset	Fuel Capacity (L)	Total Fuel consumed (L)	20 min Reserve Required (L)	Remaining Fuel Considering Reserve (L)	Time To Bingo (min)
1	CH-53K	4697.70	1952.24	887.00	1858.45	41.9
2	CH-53K	4697.70	1952.24	887.00	1858.45	41.9
3	AH-1Z	1561.00	1150.77	302.83	107.40	7.1
4	MV-22B	6513.00	1224.69	556.40	4731.91	170.1
5	CH-53K	4697.70	890.01	887.00	2920.69	65.9
6	CH-53K	4697.70	890.01	887.00	2920.69	65.9
7	CH-53K	4697.70	890.01	887.00	2920.69	65.9
8	MV-22B	6513.00	333.88	556.40	5622.72	202.1
9	M997A2	95.00	2.66	NA	92.34	342.0
10	M997A2	95.00	2.66	NA	92.34	342.0
11	M1165A1B3	95.00	6.10	NA	88.90	329.3
12	M1165A1B3	95.00	6.10	NA	88.90	329.3
13	M1165A1B3	95.00	6.10	NA	88.90	329.3
14	M1165A1B3	95.00	6.10	NA	88.90	329.3

7. Energy Link Analysis Conclusions

The analysis conducted at each platoon configuration validates the notion that more assets added to the model equates to higher fuel consumption. Consequently, it requires more fuel to complete a mission at a 5-Platoon level versus a 4-Platoon or 3-Platoon level. Table 41 displays the total fuel consumed for each platoon configuration as well as the total number of assets in the configuration.

Table 41. Total Assets/Fuel Consumption per Configuration

Configuration	Total Assets	Fuel Consumed (L)
3-Platoon	6	5224.49
4-Platoon	7	6432.94
5-Platoon	9	9313.56

Slight variations in mission length, or inaccurate fuel consumption rates for the variable fuel consumption element could result in the CAS element not being able to complete the mission. Examination of the CAS energy link for all three platoon configurations indicated sensitivity to the variable fuel consumption rate. On average, CAS elements would reach bingo in 3.6 minutes if the variable fuel consumption rate was off by 16%. This meant that if mission length was extended, on average, by only 3.6 minutes, then the CAS element would be required to return to SBAs.

While the loss of the organic CAS element would cause a slight increase in fuel consumption (333.08 liters to bring another asset from the SBAs), the impact to the total fuel consumption value would still only be approximately 5% on average across all three models. Table 42 demonstrates that the largest contributors to the fuel consumption total are the CH-53Ks. CH-53Ks are used for the QRF insertion and the MEDEVAC missions.

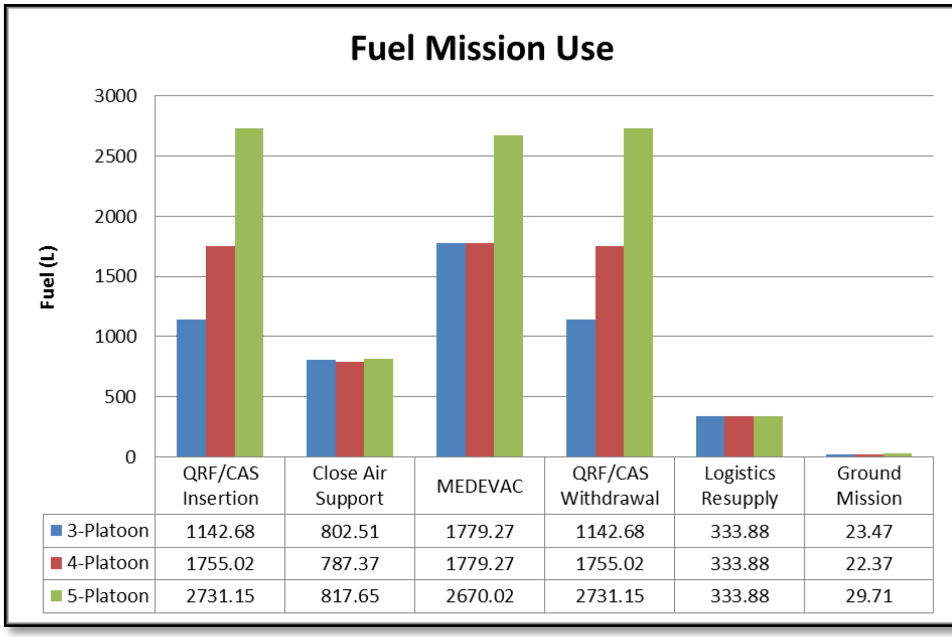
Table 42. Percent Fuel Contribution by Asset Type

	Fuel Consumption per Platoon			**Percent of Total Fuel Consumed per Platoon**		
Asset Type	**3-Platoon**	**4-Platoon**	**5-Platoon**	**3-Platoon**	**4-Platoon**	**5-Platoon**
CH-53K	3731.52	3731.52	6574.51	71.4%	58.0%	69.8%
MV-22B	333.88	1558.57	1558.57	6.4%	24.2%	16.5%
AH-1Z	1135.62	1120.48	1256.52	21.7%	17.4%	13.3%
M997A2	5.32	5.32	5.32	0.1%	0.1%	0.1%
M1165A1B3	18.15	17.04	24.4	0.3%	0.3%	0.3%

Table 42 also indicates that the CH-53Ks comprise approximately 60%-70% of the total fuel consumption for the entire mission at each platoon configuration level, and as such, a reduction in use will contribute to a significant reduction in fuel consumed during each of the mission configurations. Given the requirement to transport the QRF to the mission area, reduction in use or elimination altogether is not an option. It is therefore apparent that the frequency/total number of MEDEVAC flights is the key energy driver for each of the configurations under test.

While it would be possible to utilize the MV-22B in lieu of the CH-53K for QRF insertion and MEDEVAC missions in the scenarios discussed, the total number of MV-22Bs required would be nearly twice that of the CH-53Ks, thus surpassing the fuel consumption totals already established.

Figure 56 shows the sub mission fuel use for each platoon level. The QRF insertion and extraction operations had the greatest variability in fuel use between the three platoon levels. There was little variance in CAS, the supply mission, and the ground mission due to the short battle length in large part. Medical evacuation operations had modest variations.



	QRF/CAS Insertion	Close Air Support	MEDEVAC	QRF/CAS Withdrawal	Logistics Resupply	Ground Mission
3-Platoon	1142.68	802.51	1779.27	1142.68	333.88	23.47
4-Platoon	1755.02	787.37	1779.27	1755.02	333.88	22.37
5-Platoon	2731.15	817.65	2670.02	2731.15	333.88	29.71

Figure 56. Fuel Mission Use Comparison by Platoon Scale

D. MANA EXPERIMENTAL RESULTS

1. Summary Statistics

Summary statistics for MANA metrics are provided in Table 43. Each of the seven MANA metrics statistics were generated from the 1000 simulation runs over three experiments. Additional descriptive statistic detail is provided in Appendix F on page

283. Detailed statistics provided include histograms, box plots, mean, standard deviation, confidence intervals, and normal curve fitment data. The team performed the best fit analysis of the frequency data for each metric using JMP 11. In some cases JMP 11 reported a better fit that the Normal distribution, but results were not significantly different than the Normal fit. The team decided the Normal distribution data was sufficient for describing the data properly. The actionable statistical metric included the mean values also shown in Table 43. Those values have been incorporated into subsequent AoA analysis.

Additional observation of the statistical data showed a significant number of outliers in the data for many of the metrics. This phenomenon was believed to be a result of MANA boundary conditions associated with the end of the simulation behavior. The team examined end of simulation behavior and noted that as red agents near annihilation the simulation behaves abnormally. The blue force agents tend to lose ability to observe the final red agents. This can result in agents getting "stuck" behind terrain and objects thus biasing the final results and creating outliers in the data. Harvested data was examined and revealed that outliers indeed were being generated near the end of the simulation runs. The team actually reduced the end of run criteria to improve the situation, but it could not be totally eliminated.

Table 43. Summary Statistics MANA Metrics

	Battle Length X20	Blue Dead X9	Loss Exchange Ratio (Casualty) X21	Blue Injury Rate X25	Blue Fires Efficiency X23	Red Fires Efficiency X24	Loss Exchange Ratio (Casualty + Injured) X22
3-Platoon							
Mean	813.606	9.494	0.225	0.460	0.622	0.013667	0.659
Std.-Dev.	84.072	3.296	0.078	0.119	0.192	0.00408	0.118
Std.-Err Mean	2.659	0.104	0.002	0.0037	0.006	0.000129	0.004
Upper 95% Mean	818.823	9.695	0.230	0.4678	0.634	0.01392	0.666
Lower 95% Mean	808.389	9.289	0.221	0.4593	0.610	0.01341	0.651
4-Platoon							
Mean	754.451	8.702	0.161	0.538	0.651	0.01766	0.692
Std.-Dev.	54.061	2.081	0.039	0.102	0.176	0.00501	0.101
Std.-Err Mean	1.710	0.066	0.00122	0.0032	0.0055	0.000158	0.003
Upper 95% Mean	757.806	8.831	0.1638	0.544	0.662	0.01780	0.698
Lower 95% Mean	751.096	8.573	0.1590	0.531	0.640	0.01735	0.686
5-Platoon							
Mean	728.274	12.565	0.155	0.525	0.608	0.0259	0.681
Std.-Dev.	17.912	2.502	0.031	0.107	0.182	0.00772	0.112
Std.-Err Mean	0.566	0.079	0.00098	0.0034	0.006	0.000244	0.0036
Upper 95% Mean	729.386	12.720	0.157	0.531	0.619	0.0264	0.688
Lower 95% Mean	727.162	12.410	0.153	0.518	0.597	0.0254	0.674

2. Variance Analysis

Variance was analyzed using JMP 11 pursuant to gathering evidence regarding statistical hypothesis tests made in the Chapter IV.F.2.c. The team performed the one way ANOVA for the three levels representing the three MANA scale experiments. The

ANOVA was repeated for each of the seven MANA metrics and full results gathered and presented in Appendix F on page 283. The ANOVA F-test provides a means to determine if enough evidence exists to reject the null hypothesis that all means are equal. A finding that did not reject the null hypothesis would suggest that there was not enough statistical evidence to conclude that variation in means between levels were not due to anything other than chance. Alternatively, a finding of sufficient evidence to reject the null hypothesis would suggest the variance between levels is much greater than variance within a level (Geoffrey and Steiner 2003). In this case the variations in mean values would not be due to random chance. This was the desired result. Table 44 shows that all seven MANA metrics exhibit this characteristic as shown by the large F-test values and low P-values.

Table 44. ANOVA Results MANA Metrics

Metric	F-Ratio	P-value
Battle Length X20	555.9788	< 0.0001
Blue Dead X9	582.1903	< 0.0001
Loss Exchange Ratio (Casualty) X21	528.4138	< 0.0001
Blue Injury Rate X25	142.3129	< 0.0001
Blue Fires Efficiency X23	14.1156	< 0.0001
Red Fires Efficiency X24	1159.556	< 0.0001
Loss Exchange Ratio (Casualty + Injured)X22	23.0297	< 0.0001

3. Experimental Hypotheses

The DOE (IV.F.1) defined three experimental hypotheses derived from the research questions. This section compares the team's expectations with the actual results.

a. Experimental Hypothesis One: Result

The team hypothesized that there was a discoverable threshold energy cost associated with the execution of a successful USMC expeditionary mission. That is, there is an energy cost below which the mission will fail and above which the mission will succeed. Based on the definition of success in Chapter III.C.4 and the subsequent analysis of Chapter V.E, this could not be determined by the study. The team was not able to infer a threshold level due to insufficient experimental data.

b. Experimental Hypothesis Two: Result

The team hypothesized that variations in force scale would have an impact on the operational effectiveness of that force and the energy costs associated with its employment such that increases in scale would increase both operational effectiveness and operational energy use. Based on analysis in Chapter V.E this was found not to be true all the time. While increased scale most certainly increased energy cost, it does not always increase effectiveness.

c. Experimental Hypothesis Three: Not Pursued

1. Experimentation Goals

Four goals for experimentation were present in Chapter IV.F.2.a. The outcomes were as follows. The team pursued stable frequency statistics for the seven MANA metrics to meet goal one. Goal one was accomplished as demonstrated by the examination of statistical data. In support of goal two, the team sought to understand the impact of random variable inputs on the outputs in the MANA models. Goal two was accomplished through the observation of frequency data in the descriptive statistics. Frequency data quantitatively revealed the stochastic nature present due to input conditions; and revealed anomalous behavior of the simulations near the end run boundary. In goal three, the primary objective of the trade study, the team sought to expose the relationship between operational energy and operational effectiveness by demonstrating scale between the three levels of the experiment. This was accomplished as described throughout section E. Finally, goal four was not accomplished due to an inadequate quantity of experimental data points. The team was not able to infer a threshold success level which was related to OMOEs based on the success definition defined in Chapter III. In terms of the criteria stated, all three platoon operations were found to be successful.

2. Combined Energy and MANA Results

Table 45 depicts the final statement of MANA metrics combined with energy link data that the team used to perform the trade studies in Chapter V.E.

Table 45. Combined Fuel & MANA Measures

3-Platoon	4-Platoon	5-Platoon	Definition	Metric
5224	6433	9314	Total Fuel (L)	X0
814	754	728	Battle Length (s)	X20
9.5	8.7	12.6	Blue Dead	X9
22.5%	16.1%	15.5%	Loss Exchange Ratio (Casualty)	X21
46%	54%	52%	Blue Injured % of Total Blue	X25
62%	65%	61%	Blue Fires Efficiency	X23
1.4%	1.8%	2.6%	Red Fires Efficiency	X24
66%	69%	68%	Loss Exchange Ratio (Casualty + Injured)	X22

E. TRADESPACE ANALYSIS

1. Introduction to Trades

This tradespace analysis includes examination of those elements necessary to determine a successful mission and of supplementary experimental results used for analytical purposes to gain additional insights. All results from MANA experiments indicated in the Figure 47 are addressed in terms of the associated findings for the following key analyses.

- Loss exchange analysis
- Fires efficiency analysis
- Injury rate analysis
- Sensitivity analysis
- Battle length analysis

A successful mission determination was made on the basis of combining experimental results with results by analysis. A combination of the Analytical Hierarchy Process (AHP) and Multiple Attribute Decision Analysis (MADA) was used to support this determination. Finally, conclusions about all results from this analysis were drawn (Goodwin and Wright 2009).

2. Experimental Analysis

a. Loss Exchange Analysis

Loss Exchange Rate (LER) analysis considered the blue force percentage losses as a ratio of the red force percentage losses. This method is useful for measuring outcomes in attrition warfare (Darilek, Perry, et al., Measures of Effectiveness for the Information-Age Army 2001). The MANA modeling demonstrates attrition warfare because of the manner in which the simulation end state criteria were prescribed. Each experiment was set to end when 85 of a total 100 red forces were annihilated. Figure 57 depicts a casualty LER percentage efficient frontier. It is clear from the plot that diminishing returns are present as energy costs are increased. The 4-Platoon level is the best choice based on lowest casualty count and second best LER. Figure 58 depicts an additional LER constructed to include injuries in the ratio along with casualties. When injuries are added it becomes clear that the LER values increase substantially due to the high blue injury rates (Table 45). Although this is considered a negative outcome, LER values less than one are still consistent with the near annihilation of the red force in each experiment. The high blue injury rates were believed to be a result of the close in battle mode used with limited TTP and SA implementation in the models. Consequently, there is not a meaningful energy trade regarding LER when injury counts are included.

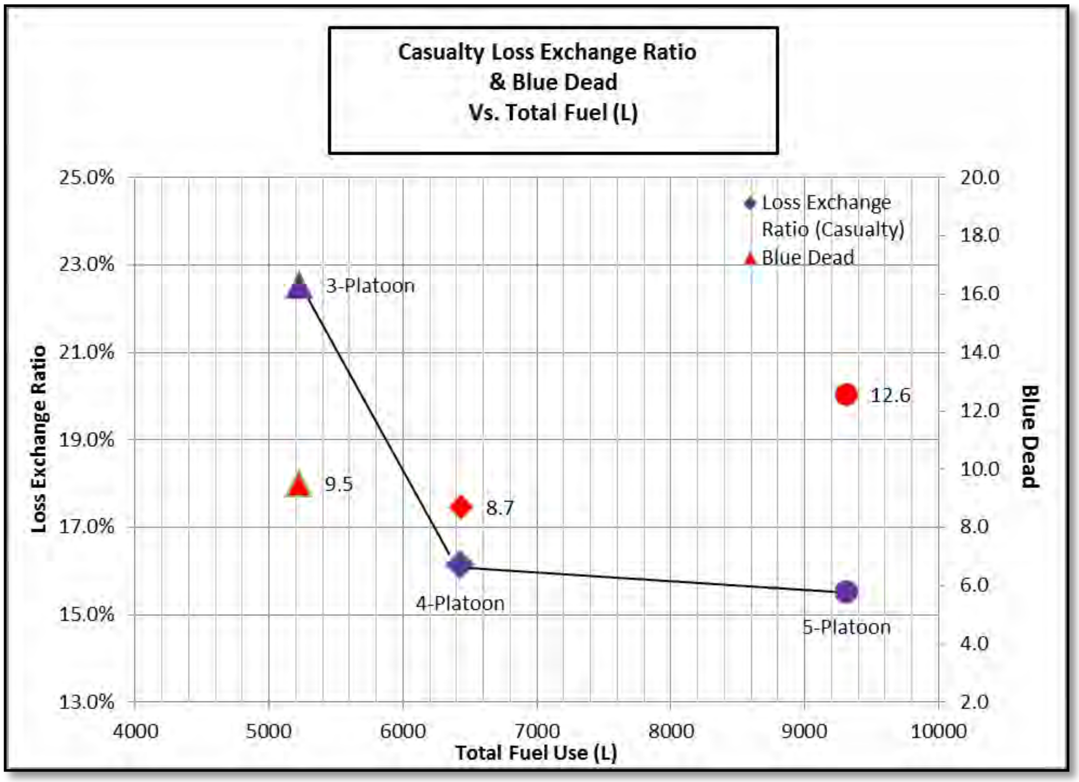


Figure 57. Loss Exchange and Blue Casualties

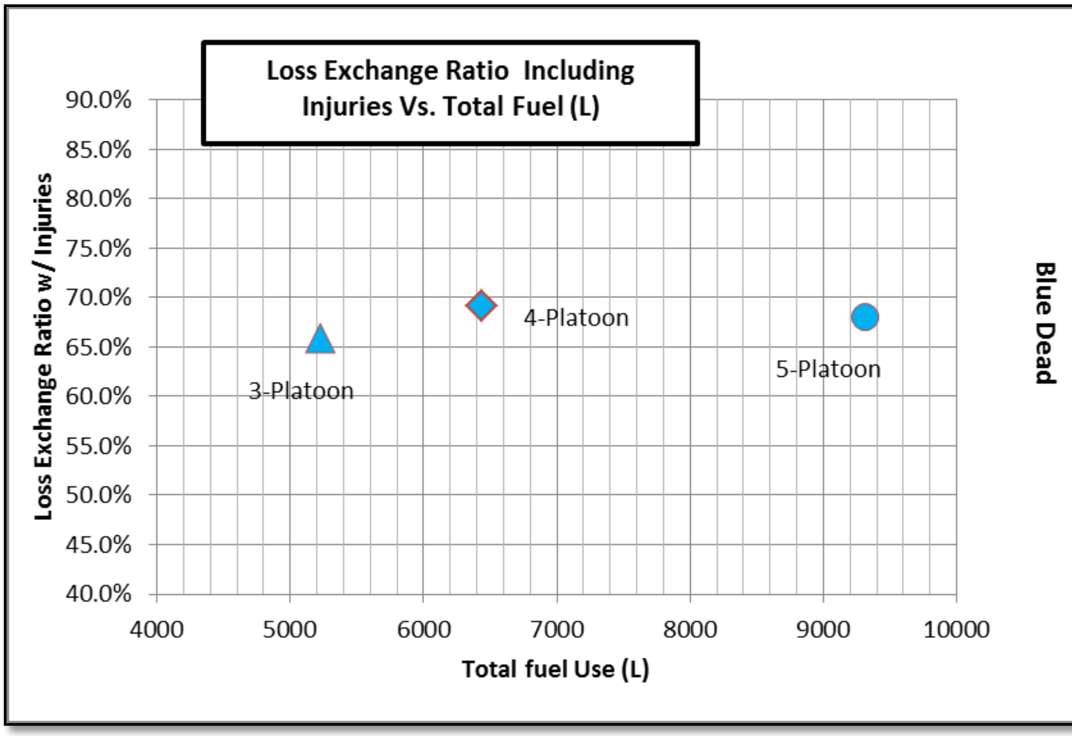


Figure 58. Loss Exchange Including Injuries

b. Fires Efficiency Analysis

Fires efficiency metrics were used to examine how well forces directed fire and hit their targets. These outcomes are a function of the stochastic nature of the weapons profiling. Additional fidelity was not present since the team did not have adequate time to implement stochastic sensor profiling. The results presented make two points. First, fires efficiency for the blue force is dramatically greater than that of the red force at each scale level. This can be explained by two features incorporated into the modeling. Weapons targeting (probability of kill) was given a slightly lower capability for the red force than for the blue force; and most importantly, armor capabilities of the blue force were considerably more effective than those of the red force. Hits are not counted when armor thickness is greater than the armor penetration ability of the weapon. It is noteworthy that the MANA modeling did not incorporate any mechanism for the agents to appropriately direct their own fires capability in accordance with the armor protection ability of the adversary. This may be possible through implementation of advanced MANA modeling properties, although time did not permit it in this capstone project. The second point of the fires analysis is that there is a minimal degree of separation of the data points between the three platoon levels. This suggests that the blue to red efficiency relationship is operative at all levels and that it is a fundamental aspect of the engagement. Review of Figure 59 shows that blue forces dominate the red in this regard. There is not a specific conclusion from this chart regarding energy trades.

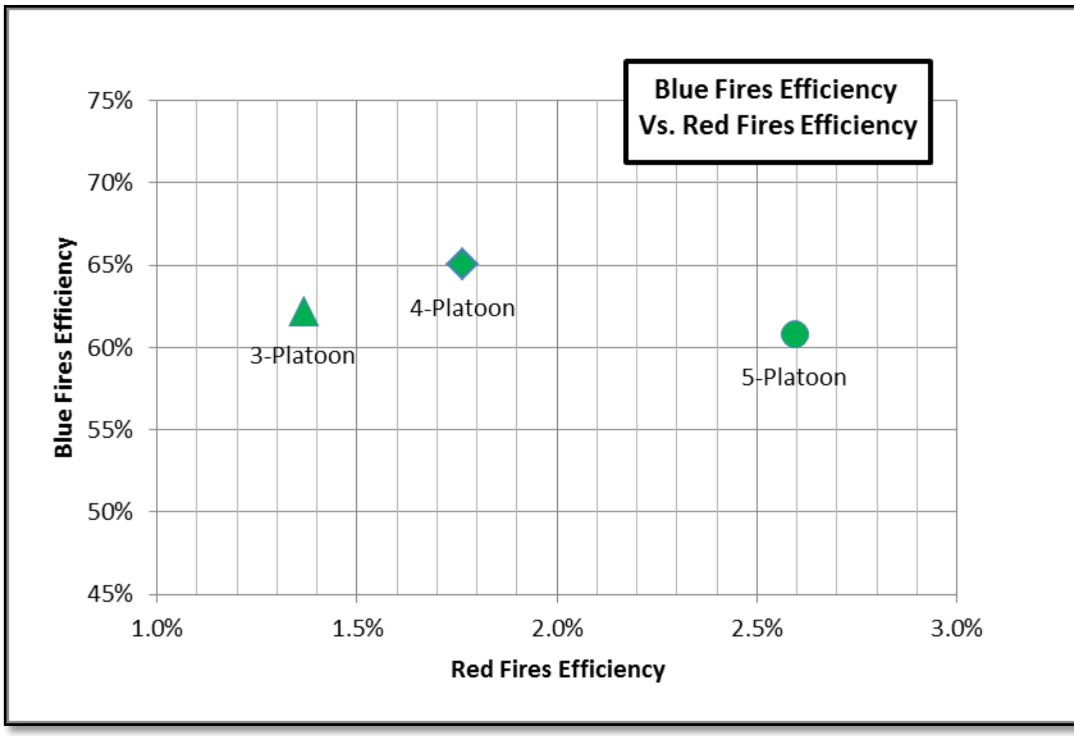


Figure 59. Blue and Red Force Hit Efficiencies

c. Injury Rate Analysis

Blue force injury rates are plotted as a function of the red fires efficiency in Figure 60 to gain insight into the high blue force injury rates that existed in each experiment. The measure is a key element in determining ACE asset requirements for conduct of the post mission medical evaluations. The chart shows that very low red fires efficiency is still adequate to cause significant injuries to the blue force. This suggests the red force has both adequate SA of the blue force and a considerable amount of ammunition. Review of the MANA harvested data files showed both to be true.

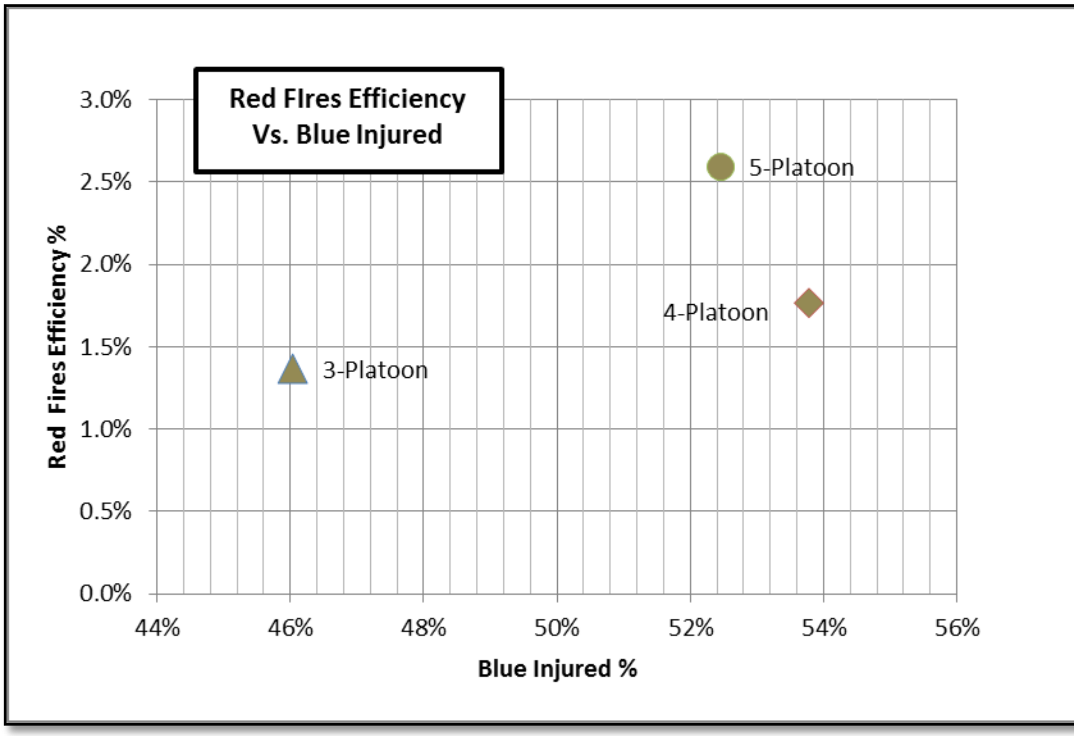


Figure 60. Blue Injury Rate

d. *Sensitivity Analysis*

A sensitivity analysis was performed to examine the sensitivity of the blue injury rate to the red fires efficiency given the ammo levels expended by the red force in the MANA requirements. A second sensitivity analysis was performed to examine the sensitivity of the blue injury rate to red ammo expended given the stated red fires efficiency provided by the MANA experiments.

In the first sensitivity analysis, the experimental data was used to imply a slope for the Blue injury rate to Red fires efficiency relationship. Figure 61 suggests that blue injury rates are very sensitive to the red fires efficiency for all three platoon configurations, although the 5-Platoon case shows the least sensitivity. The team attempted to determine why there were so many blue injuries with this low rate of red fires efficiency. This was explained in part by the high ammo levels expended by the red force. Figure 62 was conducted to examine how expended rounds by the red force might affect the blue injury rate. The chart was built to expose the red ammo expended levels required at the blue injury rate boundaries of zero and one hundred percent. The figure may inform mitigation of the blue injury rates through a combination of red force attrition, blue force TTP, and superior blue force SA. For example, according to the chart, if the blue forces take actions which reduce the red force ammo expended to below 3000 rounds, then the blue force injury rates fall below 10%. Alternatively, if the blue forces do not take appropriate actions during the engagement, then the red forces can inflict significant injury. An upper limit to blue force injury rate is determined by the ability of the blue force to either attrite the red forces thereby denying their ability to deliver rounds, or avoid observation by the red forces thereby denying them the opportunity through concealment.

The team believed the injury rate data suggested that the form of the engagement was the ultimate cause of the high blue force injury rates. Inorganic SA techniques, which were not modeled, may have provided a mechanism to enable improved blue force battle space understanding. Furthermore, with superior battle space SA, the blue force would be in a position to dominate the red force through TTP without sustaining injury rates. In lieu of that, the actual engagement more closely resembles attrition warfare. The expectation is that a smartly prosecuted engagement would actually increase battle time but reduce blue force injuries. Both battle time and injury rates have implications to the energy study. Injury rates are the dominant factor in terms of energy cost as casualty evacuation requires CH-53K support.

Figure 61. Blue Injury Rate Sensitivity to Red Fires Efficiency

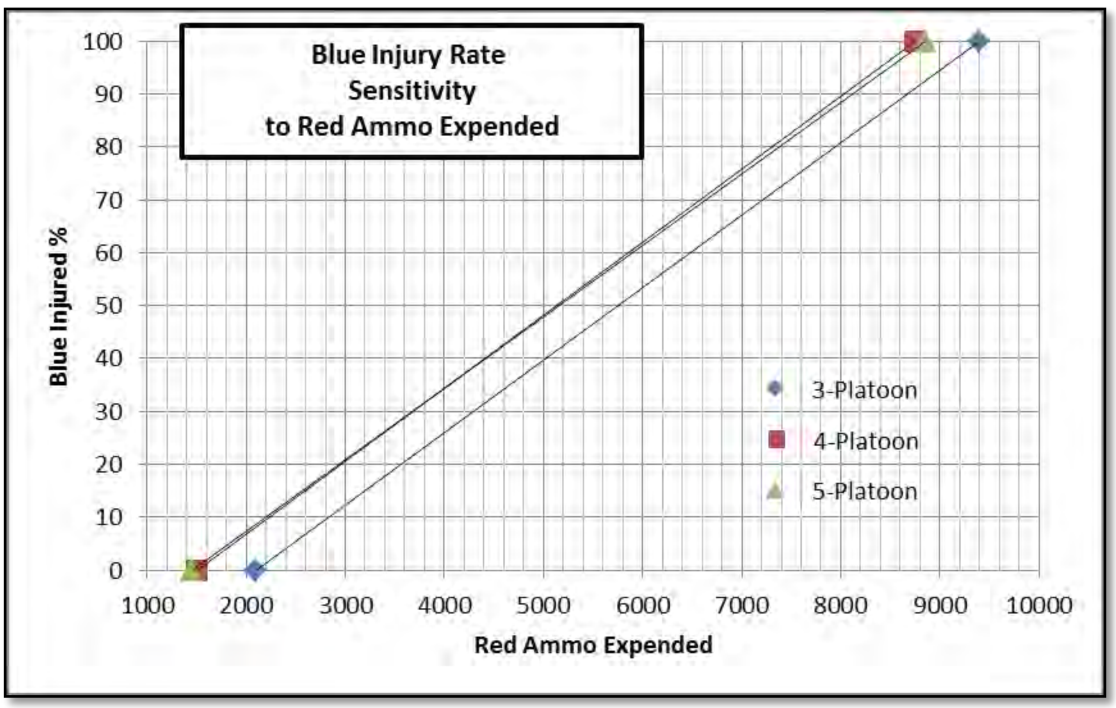


Figure 62. Blue Injury Rate Sensitivity to Red Ammo Expended

e. Battle Length Analysis

The battle length metric describes a necessary component for evaluation of the overall energy link because it determines the length for ACE battle support. Figure 63 demonstrates a key attrition warfare result. The superior capability of the blue forces with respect to weapons and armor suggest that battle length is simply a matter of how many better equipped blue troops are in the battle. It is a noteworthy finding that a diminishing return similar to the LER plot exists in this plot. This was an expected outcome based on their similar application to attrition warfare. The 4-Platoon level is the best choice based on dominance of the 5-Platoon level on an energy basis and its superior effectiveness over the 3-Platoon level.

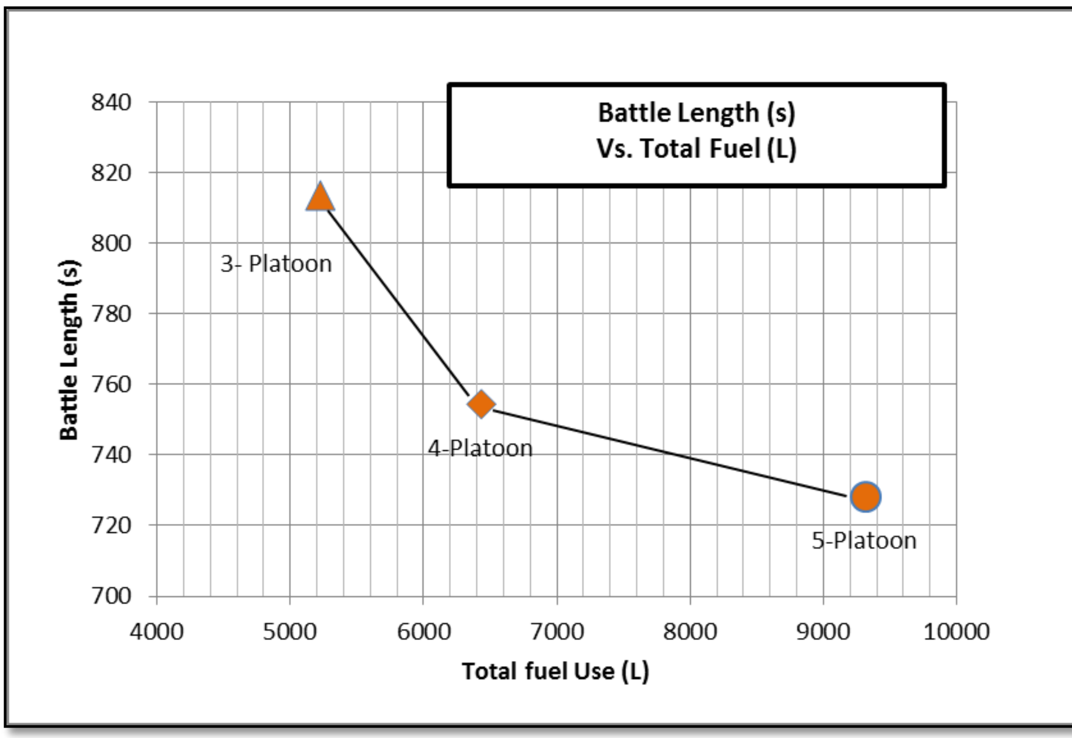


Figure 63. Battle Length vs. Total Fuel

3. Successful Mission Determination

A successful mission determination was supported through the development of an efficient frontier trade study on the operational energy versus OMOE for each platoon size. This section describes the process the team employed to acquire the result, provides analysis of the result and makes the final success determination based on criteria stated in Chapter III.

a. Combined OMOE Rollup

Table 46 shows restated MOE results for each of the three scale levels. Results, threshold and objective specifications, criticality, and data collection method were all used to determine the final OMOEs in support of the operational energy versus operational effectiveness tradespace plot shown in Figure 64. The Analytical Hierarchy Process (AHP) was combined with Multi Attribute Decision Analysis (MADA) to generate the final OMOE values for each platoon scale. The detailed AHP and MADA charts are provided in Appendix G on page 291. The steps of the process and rational for weighting are as follows (Goodwin and Wright 2009).

1. Step 1: Build MCT-3 MOE

MCT-3 had different treatment than other measures because it contained the experimentally determined sub-measure (MCT3.2.4.1-M1) in support of the direct fires mission. Ground based direct fires constituted the key experimentation element for mission effectiveness determination. Preference was used to construct M1 using AHP from the three MANA metrics shown below. Casualties were seen as having the highest weight, followed by injury rates, and finally by fires effectiveness.

- X21 Loss Exchange RatioC: Preference = 5
- X25 Blue injury rate: Preference = 3
- X23 Blue fires efficiency: Preference = 1

Next, AHP was performed a second time to obtain weights for all MCT-3 sub-measures using a preference of five to one for (MCT3.2.4.1-M1) versus the other MCT-3 sub-measures. The preference was supported by the team’s assessment of the importance of the experimentally determined ground fires mission relative to analytically determined elements of the same. A final MCT-3 score was generated for each of the three platoon scales using MADA.

2. Step Two: Build MOEs (MCT-1, MCT-2, MCT-4, MCT-5, MCT-6)

The remaining MCT measures were generated one at a time using the following process. AHP was performed to obtain weights for each of the MCT sub-measures using a preference of two to one for the critical versus non-critical measures. A final MCT score was generated for each of the three platoon scales using MADA.

3. Step Three: Final OMOE Generation

OMOE Generation was accomplished by first performing yet another AHP to incorporate a final preference of five to one for the MCT3 task and then combining the final set of six MCTs into a composite OMOE for each of the three platoon levels. The preference was supported by the team's assessment of the importance of the largely experimentally determined fires measures relative to the other five warfighting measures which were determined analytically.

Table 46. Combined MOE Results (after United States Marine Corps 2014)

	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Results			Method
					Model 1	**Model 2**	**Model 3**	
MCT 1.3.4.1.1 Conduct Airborne Rapid Insertion/Extraction								
M8	Time	To provide extraction operation.	30 min / 25 min	N	27 min	27 min	27 min	Analysis
MCT 1.6.5.11 Conduct Quick Reaction Force Operations								
M1	Percent	Force required for Quick Reaction Force operations.	100% / 75%	N	100%	95.3%	93.8%	Analysis
M2	Time	Quick Reaction Force reaction time.	15 min / 15 min	Y	15 min	15 min	15 min	Analysis
MCT 1.6.11.3 Conduct Screen Operations								
M3	Percent	Of enemy troops detected before they could come into contact with friendly flanks or rear areas.	90% / 100%	N	100%	100%	100%	Analysis

	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Results			Method
					Model 1	Model 2	Model 3	
M4	Percent	Of enemy troops detected which were engaged by fire support or maneuver assets before they could come into contact with friendly flanks or rear areas.	95% / 100%	N	98.70%	97.40%	96.30%	Analysis
MCT 2.1.1.5 Support Targeting								
M1	Y/N	Targets assigned relative value.	N / Y	N	N	N	N	Analysis
M3	Percent	Of targets available for striking.	75% / 100%	N	100%	100%	100%	Analysis
M9	Y/N	Maintain display of current enemy situation with target locations and priorities.	N / Y	N	Partially met	Partially met	Partially met	Analysis
M14	Incidents	Of Blue-on-Blue engagements.	3 / 0	Y	0	0	0	Analysis
MCT 2.1.1.6 Support Combat Assessment								

	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Results			Method
					Model 1	Model 2	Model 3	
M5	Y/N	Intelligence capable of being acquired to support Assessment (e.g., COMCAM, Imagery, SIGINT, HUMINT, CA, etc.).	N / Y	N	Y	Y	Y	Analysis
MCT 3.2.3.1.1 Conduct Close Air Support (CAS)								
M4	Number	Of sorties daily sustained during contingency/combat operations.	1 / 2	N	1	1	1	Analysis
MCT 3.2.4.1 Conduct Direct Fires								
M1	Percent	Of targets attacked with desired effects.	16% / 46%	Y	26.4	43.5	45.7	Experimental
M5	Y/N	Take the enemy under fire using lethal and nonlethal gunfire delivered on target.	N / Y	Y	Y	Y	Y	Analysis
M6	Number	Of missions completed.	1 / 2	Y	1	1	1	Analysis
MCT 4.3.8 Conduct Air Logistic Support								

	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Results			Method
					Model 1	Model 2	Model 3	
M5	Number	Of sorties daily sustained during contingency/combat operations.	0 / 1	N	1	1	1	Analysis
M8	Percent	Of required support material distributed at the time and place required.	90% / 100%	N	100%	100%	100%	Analysis
MCT 4.5.5 Conduct Casualty Evacuation								
M6	Hours	From wound or injury until person is in surgery or other appropriate care.	2 / 1	Y	.92 hours	.92 hours	1 hours	Analysis
MCT 5.3.1.2 Exercise Tactical Command and Control								
M3	Percent	Of units responding appropriately to orders.	95% / 100%	N	100%	100%	100%	Analysis
MCT 5.3.4.4 Coordinate Ground Surface Fires								
M1	Number	Of targets successfully engaged.	90% / 100%	Y	98.70%	97.40%	96.30%	Analysis
MCT 5.3.4.5 Coordinate Close Air Support (CAS)								

	Type	Description of Measure	Threshold / Objective	Critical (y/n)	Results			Method
					Model 1	Model 2	Model 3	
M8	Minutes	Of on-station time of CAS support.	60 min / 30 min	Y	53 min	52 min	54 min	Analysis
MCT 6.1.1.5.3 Conduct Patrolling								
M1	Incidents	Of friendly operations degraded due to enemy observation, detection, interference, espionage, terrorism and/or sabotage.	1 / 0	N	1	1	1	Analysis
M2	Incidents	By enemy troops, or partisans, affecting security of force and means in the operations area.	1 / 0	N	1	1	1	Analysis
M9	Y/N	Urban patrolling conducted.	N / Y	Y	Y	Y	Y	Analysis

b. Operational Energy versus Operational Effectiveness Analysis

Figure 64 depicts the efficient frontier represented by OMOE values for each platoon level and their associated energy requirements. The team believed it had exposed a relationship between operational energy and operational effectiveness embodied in this chart. The chart shows that the 5-Platoon level is nearly dominated by the other two options. Additionally, review of the casualty data suggested that more casualties occurred in the 5-Platoon case despite the fact the loss exchange ratio was slightly better. The 3-Platoon level represented the lowest effectiveness of the three options, although in terms of effectiveness per total fuel use it had a similar result to the 4-Platoon configuration. If a higher energy cost is considered acceptable so long as it provides a significant improvement in the OMOE, then it follows that the 4-Platoon level is preferable to the other options.

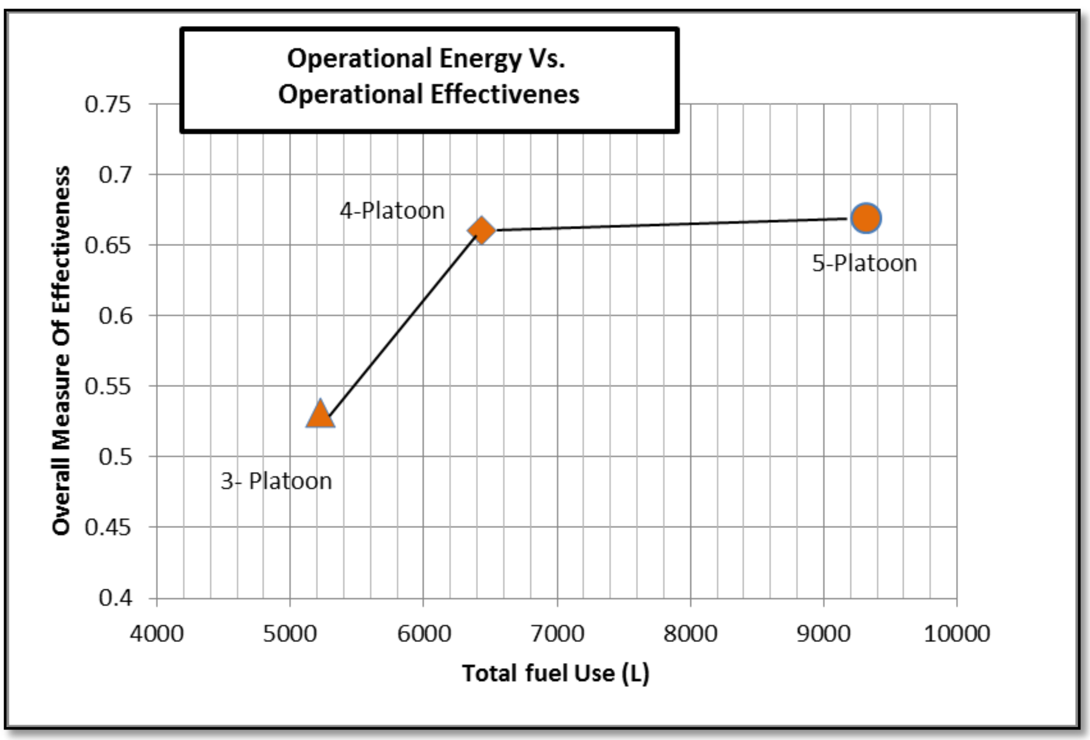


Figure 64. Operation Energy Versus Operational Effectiveness

c. Success determination

Chapter III established the criteria for the successful execution of the expeditionary mission represented by the Barra Vignette 3 Spiral One definition. The criteria stated that a mission is successful if it met all critical measures and at least 50% of the non-critical measures. Of the 23 measures indicated in Table 46, all three platoon levels met all measures with the exception of one non-critical measure (MCT2.1.1.5-M9). Based on the established criteria all three platoon level operations were considered successful. The team recognized that this method of success determination was not meaningful without additional experimentally-determined results to provide a more robust tradespace representation. Consequently, a success level could not be drawn on the operational energy chart; nor could the threshold success level be inferred.

4. Tradespace Summary Results

Summary results of the tradespace analysis include the following.

1. Tradespace Analysis Result 1

Casualty LER results suggest that diminishing returns are present as energy costs are increased. The 4-Platoon level offers the lowest casualty count and second best LER for a marginal increase in total fuel over the 3-Platoon level, which has the lowest total fuel use.

2. Tradespace Analysis Result 2

When injuries are added into the LER calculation it becomes clear that the LER values increase substantially due to the high blue injury rates. The high blue injury rates were believed to be a result of the close in battle mode used with limited TTP and SA implementation in the models.

3. Tradespace Analysis Result 3

Fires efficiency for the blue force is dramatically greater than that of the red force at each scale level, because weapons targeting (probability of kill), armor protection, and armor penetration of the blue force were all superior to those of the red force.

4. Tradespace Analysis Result 4

The minimal degree of separation of the data points between the three platoon levels for fires efficiency suggests that the blue to red efficiency relationship is operative at all levels and that it is a fundamental aspect of the engagement

5. Tradespace Analysis Result 5

Injury rate analysis shows that very low red fires efficiency is still adequate to cause significant injuries to the blue force. This corroborated the fact that the red force had both adequate SA of the blue force and expended a considerable amount of ammunition.

6. Tradespace Analysis Result 6

Injury rate sensitivity analysis shows that blue injury rates are very sensitive to the red fires efficiency for all three platoon configurations, although the 5-Platoon case shows the least sensitivity. Additionally, red force ammo expended must be reduced to below 3000 rounds (by actions of the blue force) to reduce blue force injury rates below 10%. The sensitivity data suggested that attrition warfare was operative in the MANA experiment and that additional SA modeling techniques were appropriate to demonstrate realistic battle space understanding to include force protection while dominating the engagement.

7. Tradespace Analysis Result 7

The superior capability of the blue forces with respect to weapons and armor suggest that battle length is simply a matter of how many better equipped blue troops are in the battle. More troops generally equates to reduced battle length.

8. Tradespace Analysis Result 8

Diminishing returns similar to the LER result exists with regard to the battle length versus energy trade. The 4-Platoon level is dominant over the 5-Platoon level. Additionally, the 4-Platoon level offers superior effectiveness over the 3-Platoon level at a marginal increase in total fuel use.

9. Tradespace Analysis Result 9

OMOE versus energy shows that the 4-Platoon level offers the best overall alternative in the trade study. The 5-Platoon level is nearly dominated by the other two options. Review of the casualty data also suggested that more casualties occurred in the 5-Platoon case despite the fact the loss exchange ratio was slightly better. The 3-Platoon level represented the lowest effectiveness of the three options although in terms of effectiveness per total fuel use it had a similar result to the 4-Platoon configuration.

10. Tradespace Analysis Result 10

The successful mission determination showed that all missions are successful according to the criteria established, but the team did not accept the determination as adequate due to lack of robust experimental results for all dimensions of the war fighting spectrum.

F. CHAPTER SUMMARY

The AoA was supported by a framework discussion that assessed the methods, sources, and measures from which the AoA was performed. Additionally, the framework revisited the initial research questions and the mission success criteria in an effort to understand what steps would be necessary to complete the analysis. Questions one and two were pursued with the understanding that available experimental data limited the ability to examine all the trades associated with the six dimensions of the war fighting spectrum. The team decided that a restatement of the MOEs, combined with the use of experimental and analytical means would support a limited examination of the tradespace. The MOEs were restated and traced to the methods employed for the study, function elements, requirements, and the effective need. Final MANA metrics were also traced to the operative experimentally supported MOE as well as to the dependencies in the constructed metrics within the MANA output. A final tradespace hierarchy was presented to further articulate the relationship between experimental results, results by analysis, and the successful mission determination.

A mission energy link analysis was performed to support the trade study. The energy link analysis frames the study in terms of fixed and variable consumers in the battle space so that energy dependencies associated with the battle engagement could be quantified. Certain MANA outputs, such as battle length, blue agents killed, and blue agents injured were identified as key dependencies for the energy study. A base set of assumptions that corresponded to all three experiments were stated. The assumptions assisted in defining holistically the entire energy link associated with full mission. This provided the necessary augmentation to the autonomous MANA modeling. Given base assumptions the energy study continued to develop full estimates analytically for the energy requirements corresponding to each of the three platoon sizes. An energy profile vs. time was created in each case showing consumption rates at each interval as well as cumulative energy consumption. Analysis by asset, mission, and fuel availability was performed to fully describe the energy space.

Energy link analysis findings included the determination of total mission fuel for each of the three platoon levels as well as contribution by asset type in all cases. Additional findings related the dynamics of the mission on the ground to the ACE energy need to support it. CAS asset requirements, which are closely coupled to the battle engagement length, are particularly susceptible to running out of fuel during on-station time required. Medical evacuation requirements were found to be the single largest driver of fuel requirements in the Barra scenario based on the CH-53K aircraft use. Therefore, injury rates played a key role in determination of the total mission fuel for each platoon level.

MANA experimental results were examined for statistical significance and to make a determination as to the suitability for using mean values in the trade study analysis. Results reveal that the Normal distribution represented a suitable fit to the frequency data for each of the seven MANA metrics although some outliers were found to be results of anomalous MANA boundary condition behavior. Additionally, ANOVA results revealed high F-test values demonstrating strong evidence in support of rejecting a hypothesis that means across the three experimental scale levels were from the same population. This further supported the use of the experimental data in the trade study. Experimental hypotheses and goals were revisited to state results. The hypothesis regarding thresholds success could not be determined due to insufficient experimental data. The hypothesis that increased force would increase both operational energy and operational effectiveness was found to be partially true. The study in fact determined this was not always the case. Three of the four experimental goals were achieved further supporting the prosecution of the trade study.

The tradespace analysis was conducted by examination of key relationships uncovered when the energy link analysis data was combined with experimental results from the MANA data. Key results have been summarized in Chapter V.E.4.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSIONS

A. INTRODUCTION

This capstone project involved the specification, modeling, execution, and data analysis associated with the operational effectiveness and energy efficiency of a notional Marine Corp SPMAGTF unit operating in the West Africa Area of Responsibility (AOR) pursuing a screening operation in support of follow on operations of Operations Restore Sovereignty, a Title 10 War games evolution. Team Expeditionary endeavored to pursue a set of research questions, driven by the effective need of our customers, which would support the discovery of findings regarding the conduct of this expeditionary mission. A review was performed of the project activities, artifacts, and results to support conclusions. The effective need was examined to assess the degree to which the team met the customers' objectives. Research findings were stated and supported to provide a concise reference of the key findings in the project. Research questions and experimental hypotheses were answered according to findings. Future research opportunities which were uncovered through the project were presented and the connection to this capstone project identified to support extensible research. Finally, a set of recommendations regarding next steps was presented.

B. EFFECTIVE NEED

In the execution of the capstone project Team Expeditionary implemented a SE process in order to address the customers' effective need. The statement of effective need was parsed into three segments for the evaluation.

MBSE was used through the use of the ABMS tool MANA. The team constructed an executable model representing a segment of the Barra mission to support the AoA of three solutions. Materiel factors were examined by development of three scales of the SPMAGTF force. The team selected equipment from existing USMC MAGFT architecture with limited use of planned materiel. Non-materiel factors were not specifically examined as alternatives in the study. Measures for operational effectiveness and operational energy were specified to allow the evaluation of the alternative solutions performing the successful expeditionary mission. The research did uncover several findings which characterize the relationship between operational energy and operational effectiveness. These findings are further elaborated herein.

> Effective Need Segment 1: Team Expeditionary will use Model-Based Systems Engineering (MBSE) to examine both materiel and non-materiel factors regarding the conduct of an operationally effective, and energy efficient, Marine Corps expeditionary mission. Material factors will be constrained to solutions from existing and planned USMC architectures. The research will expose the relationship between operational energy and operational effectiveness in a balanced manner to support realignment of the fast, austere, and lethality objectives of the USMC.

The West Africa title 10 war game described in EW12 (Operation Restore Sovereignty) was used for the CONOP development in this capstone project. Operation Restore Sovereignty was representative of the type and scale of irregular warfare activities the USMC is commonly involved in and anticipated to be in for future warfare (Marine Corps Warfighting Laboratory 2012). The team considered this war game evolution particularly appropriate because it provided multiple ways to support extensible research. This was discussed further herein.

> Effective Need Segment 2: The MBSE may use existing Title 10 War Games evolutions to the extent practical and which allows the continued development of extensible research. In the conduct of MBSE the team will gain an understanding of the operational energy consumption of the current and future force structure in an operational context that is representative of existing and anticipated environments.

Team Expeditionary developed tactical objectives, assumptions, and mission intent statements for three separate vignettes within the follow on operations overarching mission of Operation Restore Sovereignty. Vignette 3 (Barra Screen) was further developed to account for MEB concepts of operation which support integration of air, land, and seas assets in the battle space (United States Marine Corps 2014). Vignette 3 was robust, supporting three segment opportunities for modeling. The opportunities are discussed further herein. The modeled segment ultimately did allow data farming, and evaluation of alternatives with respect to energy and effectiveness. This capstone supported existing and continuing research efforts at NPS and those of the E2O. Capability gaps were not assessed at this time; however, continued research which is proposed herein may use this research foundationally in pursuit of filling specific capability gaps.

> Effective Need Segment 3: The team will develop a robust operational context to support both the modeled and un-modeled scenarios. Support for the modeled scenario will be adequate to enable farming of operational energy and operational effectiveness data sufficient to facilitate an understanding of the tradespace. Whether modeled or un-modeled the robust operational context will provide foundational support for future research, benefit existing research efforts in the energy community and provide input for capability gap re-assessment.

C. SUMMARY RESEARCH FINDINGS

The team summarized findings associated with the combined operational effectiveness and operational energy predictions determined by the MANA experiments and energy link analysis. These findings were presented with the understanding that they were based on the nature of the assumptions, experiments, and analysis described extensively throughout this capstone report. Findings are those of Team Expeditionary alone and the fitness of these findings for any particular purpose shall be determined by the reader.

The summary includes findings which describe outcomes of the ground fires prosecution by the blue force (CJTF), energy aspects regarding the support of that ground fires mission, and the individual and overall trades associated with engagement.

a. Research Finding #1: Key Energy Drivers in the Analysis

The analysis confirmed the intuitively obvious notion that larger scale operations require more energy to complete. The relative contribution of energy drivers at each scale and each sub-mission provided additional understanding to the obvious result. For all three scale levels the QRF insertion and extraction were the key energy drivers pre-determined by the platoon scale. For all three scale levels the MEDEVAC operation sortie rates were the key variable energy drivers based on battle outcome. The analysis further concluded that, although the CAS element had re-fuel risk, increased fuel use due to concurrent CAS sorties was small as a fraction of the MEDEVAC operation. Therefore, it seems clear that for short on-station times the fuel cost of CAS represents a small price for the reduction in MEDEVAC costs which result from CAS effectiveness. Ground Vehicle fuel use was negligible compared to ACE costs.

Additional findings were evident from examination of the platoon configuration variations in the sub-mission fuel totals. The energy analysis supported a finding that variations between the scales are driven by how many troops have to be transported, how far and fast they are moved, and for what purpose. The QRF insertion and extraction operations determine the greatest variability in fuel use between the three platoon levels. There was little variance in CAS, the supply mission, and the ground mission due to the short battle length in large part. In addition, the MEDVAC operations had modest variations.

b. Research Finding #2: Energy Dependencies in the Battle Space

The analysis revealed two key energy dependencies in the battle space, namely battle length and casualty rate. The corresponding CAS effectiveness was anticipated but not demonstrated in the MANA simulations. Effective CAS operations should have a direct impact on the ground battle progress, but this was not measured in the MANA experiments since it could not be modeled in the time allotted. The CAS fuel dependency on battle length was examined analytically. The team found that the battle length and casualty rate determined what level of support was required by the GCE from the ACE. CAS asset requirements were closely coupled to the battle engagement length. Additionally, there was a sortie rate multiplier effect since CAS sorties are particularly susceptible to running out of fuel depending on the on-station time required. The multiplier effect was not present for any of the analysis performed by the team; however, it was clear that very modest increases in battle length would result in increased CAS sorties and allocation of additional air assets to the battle. Medical evacuation requirements, which were found to be the single largest variable driver of fuel consumption, were directly determined by the casualty rates. Additionally, it was clear from the analysis that increased platoon sizes represent increased risk for injuries and therefore by association increased change for energy requirements.

c. *Research Finding #3: Economies of Scale*

On balance, increased force scale improves the effectiveness of the direct fires mission, but increases have diminishing returns in terms of the energy costs. LER and battle length analysis both suggest that increases in platoon scale do improve effectiveness for these measures. There is, however, a marked reduction in the improvement from four to five platoons. This represents a noteworthy economy of scale. Quantitatively, the LER improvement from three to four platoons on an energy use basis is 25 times greater than the improvement from four to five platoons. Similarly, the battle length reduction from three to four platoons is five times greater than the reduction from four to five platoons.

Injury rate and fires efficiency data are not necessarily improved with increasing force scale according to the MANA results. There is a minor counter-trend effect when injuries are included in the LER analysis, but the variance is small between the three platoon levels. Fires efficiency analysis examined the relative performance of the blue force over the red and showed that the 4-Platoon level was optimal, although there was also minor variance in the three levels. In terms of injury rates, the platoon scale shows that more boots on the ground equates to more injuries. This actually reduces the effectiveness as scale is increased marginally.

d. *Research Finding #4: Battle Space Understanding*

Superior Weapons and Armor do not necessarily compensate for an inadequate battle space understanding and this impacts energy. High injury rates of the blue force occurred despite superior blue force weapons and armor characteristics; and high injury rates equated to significant energy requirements for medical evacuation. This was the counter intuitive result that prompted sensitivity analysis of the blue force injury rate. Injury rate sensitivity analysis showed that blue injury rates were very sensitive to the red fires efficiency for all three platoon configurations, and that a reduction in red force ammo expended to below 3000 rounds was needed to reduce blue force injury rates below 10%. Additional examination of the ammo data suggested that red forces were using a large proportion of their available rounds compared to the blue forces. Essentially, given an adversary with plenty of ammo and the ability and opportunity to expend it, the blue forces did not reduce their own injuries despite having superior armor and weapons. This was likely linked to the fact that there was no specific modeling implemented which is considerate of injury rates. The ground battle was one of attrition such that a lower number of better equipped blue forces eventually annihilated a higher number of less equipped red forces at a cost of high injury rates. It is clear that a combination of model design properties had a bearing on this outcome. Recall that agent movement propensities were configured to balance the affinity toward objective waypoints and enemies. Additionally, agents SA were configured such that agents had the ability to observe the enemy at the squad level only. Since all squads were configured for cohesive movement, there was no significant overall understanding of the battle space. Additionally, communication links were not setup between squads to facilitate smart tactics in the progression of the battle. Although it is true that the lack of these modeling elements suggests a lack of fidelity the result has also provided a clear finding that superior weapons alone are not enough.

D. RESEARCH QUESTIONS REVIEWED

The research questions were reviewed for original intent, the team's experimental hypothesis, method of measurement, and results.

1. Question 1 (Threshold Success)

The objective for the question of threshold success was to determine (through experiment or analysis) what the exact effectiveness threshold was for the successful completion of the USMC expeditionary mission. The team hypothesizes that this threshold was discoverable and further suggested that a specific energy cost could be determined analytically which yielded the exact threshold effectiveness on an efficient frontier. In order to isolate the level, construction of the efficient frontier was necessary.

This proved to be a difficult task. The team was not able to obtain adequate experimental data to fully elaborate the effectiveness in all six dimensions of the war fighting spectrum. In terms of the ground fires function (the one experimentally determined outcome) the LER and battle length plots do portray an efficient frontier. Threshold success may have been inferred on those plots if a narrow set of MOEs were used.

2. Question 2 (Dynamic MEB Scaling)

The second question required the determination of a relationship between operational effectiveness and operational energy. The team hypothesized that increasing force scale would increase energy requirements and effectiveness. Force scale was demonstrated experimentally through the development of three models each having different scale. Metrics were allocated, data collected, and analysis performed which did in fact uncover several force scale based relationships. These are identified in the findings with specific details in the AoA. The hypothesis was shown to be partially true. Increases in force scale do increase energy costs, but resulting effectiveness follows a law of diminishing returns. Of the three experiments, the team found that the 4-Platoon experiment yielded the best overall results despite the fact it was not the largest scale.

3. Question 3 (Operational Energy Trajectory)

The Team was not able to pursue question three although it did establish the initial data point for the inquiry. The objective of question three was to examine present and future force composition in operational contexts similar to the EW12 context and analytically determine the trajectory toward or away from the centroid of the (fast, austere, lethal) spectrum. The team made no specific hypothesis regarding the trajectory. In order to address the question each data point in that trajectory represented a unique SE problem. Therefore, it would be necessary to perform the entire SE process including modeling and DOE, and then perform tradespace analysis at each data point to infer the trajectory.

E. FUTURE RESEARCH

1. Holistic Mission Modeling

In accordance with USMC Expeditionary Force 21, the battle space should be well integrated and utilize elements of air, land, and sea effectively to support the dominance of the enemy (United States Marine Corps 2014). A key challenge and opportunity in this area is embodied by the end to end modeling of the operational environment in such a way as to capture the energy and effectiveness dependencies and the decision making associated with them. The mission analysis provided by Team Expeditionary provides significant detail to facilitate holistic mission modeling in support of this objective. The Barra Vignette in particular provided three segments which when combined allow the demonstration of enablers, progressively attained battle space SA, net-centric operations, and battle engagement. Effectively, holistic modeling allows the examination of different aspects of the war fighting spectrum including the measurement of their effectiveness and that relationship to the operational energy commitment and use. Regarding the Barra Vignette, consider that if all three segments were fully modeled, a better understanding of how energy is committed and consumed across the MAGTF and how it relates to effectiveness might emerge.

2. Net-Centric Modeling

Research finding #4 showed that Superior Weapons and Armor do not necessarily compensate for an inadequate battle space understanding and this impacts energy. It follows that a meaningful next step is incorporation of SA, C2, and organizational tactics in the battle space modeling. Lauren proposed the Fractal Attrition Equation as a meta-model to describe outcomes of cellular automaton combat models (Lauren et al. 2005). According to Lauren, the incorporation of spatial distributions in the meta-model makes it a plausible replacement for the Lanchester square law equation, which has been used to describe attrition rates in direct fire combat (Lauren et al. 2005). In Team Expeditionary's capstone study, the Barra Vignette provides the operational backdrop for spatial organization, C2, SA, and a general battle space understanding to be demonstrated.

Furthermore, with net-centricity incorporated, the Barra Vignette provides the lay down to measure the resultant effectiveness and energy benefits. Lauren proposed the following question regarding the efficacy of networking dispersed forces.

> For example, is the true value of networking dispersed units together that it allows the networked force to more ably maintain a favourable fractal dimension relative to its opponent? (Lauren et al. 2005, 32)

Therefore, In terms of the energy study, the research opportunity is to gain insight into the relationship between net-centric warfare and resulting energy efficiencies.

3. Hybrid Modeling

The team deliberated on the modeling paradigm and realized there were competing values associated with the use of DES and ABMS. On one hand DES permitted the development of a strong understanding of low interaction prescribed behavior such as found in supply chains. On the other, ABMS allowed exploration of multiple interaction environments with somewhat unknown behavioral outcome. The team realized both modeling techniques were valuable tools, but had to select one for the project. In retrospect, the team realized that the elaborate CONOP associated with Operational Restore Sovereignty lends itself to combing both modeling techniques in a hybrid modeling concept so that both known and unknown behavior can be examined together. It is not clear how this would be accomplished yet, but the benefits could be significant provided the interfaces between the models were handled correctly.

4. Behavioral Energy Modeling

The team proposed a behavioral based energy modeling inquiry in which energy commitment decision-making affinity factors are introduced. The research opportunity requires examination of decision making in the battle space which includes energy committing along with other battle decisions. In a battle space resources are scarce and the commitment of them must be efficient and timely to ensure the desired outcome. In this paradigm one modeling objective is to identify design points which adequately characterize a tradespace based on varying agent propensities across a multi-variate behavioral spectrum. Agents and groups of agents' propensities can be set according to certain biases that define this spectrum such as, survival, victory, efficient use of resources, and so on. This allows competing values to be examined in the tradespace. In a military context behavioral based energy modeling may be a useful tool to evaluate warfighting doctrine in light of the Marine Corps present desire to return balance between fast, austere, and lethal.

F. RECOMMENDATIONS

Team Expeditionary recommends that the E2O examine artifacts of this capstone effort and assess options and priorities for continue pursuit of these topics. NPS should maintain the artifacts and examine the value of incorporating operational energy decision making into dashboard metrics. Future research investigations presented herein should be considered in terms of how they might facilitate objectives of both E2O and NPS.

The ONR S&T strategic plan was reviewed and topics in this study found to align to Expeditionary and Irregular Warfare Focus Area objectives including shared situational awareness and understanding (United States Marine Corps 2012). The alignment should be included as appropriate in similar research proposals. Capability gaps were not addressed in this study, but offer another opportunity for examining the value of inquiry represented by this study. Capability gaps related to this study should be reviewed and future research focused on completing closure of gaps. Finally, the Marine Corps Warfighting Laboratory engages in annual Title 10 war fighting games. Team Expeditionary recommends incorporation of energy dependences in annual war games development to whatever extent practical.

G. CHAPTER SUMMARY

The effective need for this capstone project was examined and the team's performance shown to be compliant with the major requirements of the effective need. Four key research findings were presented and supported with results from the AoA. Key findings included insight into key energy drivers, energy dependencies, economies of scale regarding force size, and the merit of battle space understanding. The results of the project were used to answer the research questions. The data supported adequate results to answer questions two regarding force scale, but did not provide sufficient data to answer question one (threshold success) or question three (trajectory). Future research opportunities were presented which the team considered extensions of the work done in this capstone project. Team Expeditionary proposed future research to include holistic modeling of end to end missions, incorporation of net-centricity, hybrid modeling to use multiple types of modeling paradigms, and behavioral modeling to examine decision making in scare resource environments. Recommendations for next steps were presented with appropriate suggestions for leveraging this capstone project's conclusions and artifacts.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A: SIX WAR FIGHTING FUNCTION DEFINITIONS

The Marine Corps war fighting definitions in this section support the functional decomposition from Chapter II. All war fighting definitions are taken from Marine Corps Task List (MCTL – 2.0).

MCT 1 DEPLOY FORCES/CONDUCT MANEUVER

> To move forces to achieve a position of advantage with respect to enemy forces. This task includes the employment of forces on the battlefield in combination with fire or fire potential. Maneuver is the dynamic element of combat, the means of concentrating forces at the decisive point to achieve the surprise, psychological shock, physical momentum, and moral dominance which enables smaller forces to defeat larger ones. This task includes the movement of combat and support units. (United States Marine Corps 2014)

MCT 2 DEVELOP INTELLIGENCE

> To develop that intelligence that is required for planning and conducting tactical operations. Analyzing the enemy's capabilities, intentions, vulnerabilities, and the environment (to include weather and the application of tactical decision aids and weather effects matrices on friendly and enemy systems, and terrain) derives it. This task includes the development of counterintelligence information. (United States Marine Corps 2014)

MCT 3 EMPLOY FIREPOWER

> To apply firepower against air, ground, and sea targets. The collective and coordinated use of target acquisition data, direct and indirect fire weapons, armed aircraft of all types, and other lethal and non-lethal means against air, ground, and sea targets. This task includes artillery, mortar, and other non-line-of-sight fires, naval gunfire, close air support, and electronic attack. It includes strike, air/surface/undersea warfare, naval surface fire support, counter air, and interdiction. (United States Marine Corps 2014)

MCT 4 PERFORM LOGISTICS AND COMBAT SERVICE SUPPORT

> To sustain forces in the combat zone by arming, fueling, fixing equipment, moving, supplying, manning, maintaining visibility over, and by providing personnel and health services. Includes logistic support, as necessary, to U.S. agencies and friendly nations or groups. This task includes prepositioning operations. (United States Marine Corps 2014)

MCT 5 EXERCISE COMMAND AND CONTROL

The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and Control provides the means by which a commander recognizes what needs to be done and sees to it that appropriate actions are taken. Command and Control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. This task is applicable to prepositioning operations. (United States Marine Corps 2014)

MCT 6 PROTECT THE FORCE

Protecting the force consists of those actions taken to prevent or mitigate all threats and hazards to personnel, resources, facilities and critical information. These actions conserve organizational capability so that it can be decisively applied, and sufficient equipment must be available to protect not only the uniformed force, but also the essential supporting U.S. and civilian workforce. This task includes those measures the force takes to remain viable and functional by protecting itself from the effects of or recovery from enemy activities, and when located at CONUS installations. This task includes prepositioning operations. (United States Marine Corps 2014)

APPENDIX B: MARINE CORPS TASKS FOR MODELED SEGMENT

The Marine Corps task definitions in this section support the functional decomposition from Chapter II. All task definitions are taken from Marine Corps Task List (MCTL – 2.0).

MCT 1.3.4.1.1 Conduct Airborne Rapid Insertion/Extraction

Airborne rapid insertion/extraction is the planned insertion/movement of forces conducted rapidly followed by a planned and rapid withdrawal. Helicopter Rope Suspension Techniques (HRST) provides Marines with the ability to conduct insertions and extractions where landings are impractical. Airborne rapid insertion/extraction includes methods such as rappelling, fast rope, special patrol insertion and extractions, etc. (United States Marine Corps 2014)

MCT 1.6.5.11 Conduct Quick Reaction Force Operations

To conduct quick reaction and show of force operations designed to demonstrate U.S. resolve and involve increased visibility of deployed forces in an attempt to defuse a specific situation that, if allowed to continue, may be detrimental to U.S. interests or national objectives. This task includes generating and dispersing capable forces expeditiously to the immediate threat, or vicinity of enemy forces in designated areas. (United States Marine Corps 2014)

MCT 1.6.11.3 Conduct Screen Operations

To maintain surveillance and provide early warning (primary purpose) to the main body, or impede, destroy, and harass enemy reconnaissance within its capability. To locate and maintain contact with the lead company of each suspected enemy advance guard battalion. (United States Marine Corps 2014)

MCT 2.1.1.5 Support Targeting

Intelligence supports targeting in all domains, including cyberspace, by identifying target systems, critical nodes, and high-value and high-payoff targets, as well as, by providing the intelligence required to most effectively engage these targets through kinetic and non-kinetic means. (United States Marine Corps 2014)

MCT 2.1.1.6 Support Combat Assessment

Combat assessment is the process used to determine the overall effectiveness of military operations and identify requirements for future actions, including in cyberspace. Intelligence supports the entire combat assessment process and is directly responsible for battle damage assessment (BDA), which is one of the principal components of combat assessment. BDA is the timely and accurate estimate of the damage resulting from the application of military force. BDA estimates physical and logical damage to a particular target, functional damage to that target and the capability of the entire target system to continue its operations. (United States Marine Corps 2014)

MCT 3.2.3.1.1 Conduct Close Air Support (CAS)

Close Air Support (CAS) operations are performed by fixed-wing and rotary-wing aircraft against hostile targets that are in close proximity to friendly forces. CAS requires detailed integration of each air mission with the fire and movement of friendly forces. It includes preplanned and immediate close air support (CAS) missions, positive identification of friendly forces and positive control of aircraft, and enhances ground force operations by delivering a wide range of weapons and massed firepower at decisive points. (United States Marine Corps 2014)

MCT 3.2.4.1 Conduct Direct Fires

To take the enemy under fire using lethal and non-lethal gunfire delivered on a target, using the target itself as a point of aim for either the gun or the gunner. Examples include small arms, tanks, antitank weapons, automatic weapons, and directed energy weapons. Attack helicopter fires are included here. This task includes use of direct fire with maneuver; direct fire is inherently connected to maneuver. Positioning of direct fire under firepower does not change that close relationship with maneuver. (United States Marine Corps 2014)

MCT 3.2.4.2 Conduct Indirect Fires

To apply indirect fire ground-based weapon systems to delay, disrupt, destroy, suppress, or neutralize enemy, equipment (including aircraft on the ground), materiel, personnel, fortifications, and facilities. (United States Marine Corps 2014)

MCT 4.3.8 Conduct Air Logistic Support

Air logistic support provides support of MAGTF forces by fixed-wing and tilt-rotor aircraft. Air logistic support delivers troops, equipment, and supplies to areas beyond helicopter range and lift capability or when surface transportation is slow or unavailable. This task includes prepositioning operations. (United States Marine Corps 2014)

MCT 4.5.5 Conduct Casualty Evacuation

To conduct evacuation operations designed to move patients to a medical facility capable of providing required Health Services Support (HSS). (United States Marine Corps 2014)

MCT 5.3.1.2 Exercise Tactical Command and Control

Tactical command and control provides purpose and direction to the varied activities of a military unit. It is the means by which the Commander recognizes what needs to be done and sees to it that appropriate actions are taken. Tasks include: to order warfare degrees of readiness; to direct asset assignment, movement, and employment; and, to control tactical assets, including allied and joint forces assigned. (United States Marine Corps 2014)

MCT 5.3.4.4 Coordinate Ground Surface Fires

To coordinate artillery and mortar support with maneuver of forces ashore, into a cohesive action maximizing their effect in accomplishing the mission and minimizing adverse effects on friendly/neutral forces and non-combatants. (United States Marine Corps 2014)

MCT 5.3.4.5 Coordinate Close Air Support (CAS)

To coordinate Close Air Support (CAS) with maneuver of forces ashore into a cohesive action maximizing their effect in accomplishing the mission and minimizing adverse effects on friendly/neutral forces and non-combatants. (United States Marine Corps 2014)

MCT 6.1.1.5.3 Conduct Patrolling

Patrolling is necessary to provide additional security and is either reconnaissance or combat, mounted or dismounted. A patrol is tasked to collect information, confirm or deny accuracy of previously gained information, provide security, and harass, destroy, or capture the enemy. Patrols can also fix the enemy in place by fire and movement until other forces arrive or supporting fires can destroy them. Mounted patrols are used where the unit has a larger sector to cover and few personnel to patrol, and can be used to cover gaps between units in the defense, provide flank security and coordination, patrol forward of the base perimeter to provide early warning, and assist in reconnaissance when a large sector must be covered in a short time. Dismounted patrols may be a fire team, squad, platoon or company and must be able to interact with local inhabitants but still be ready to conduct combat operations. (United States Marine Corps 2014)

APPENDIX C: FUNCTIONAL HIERARCHY

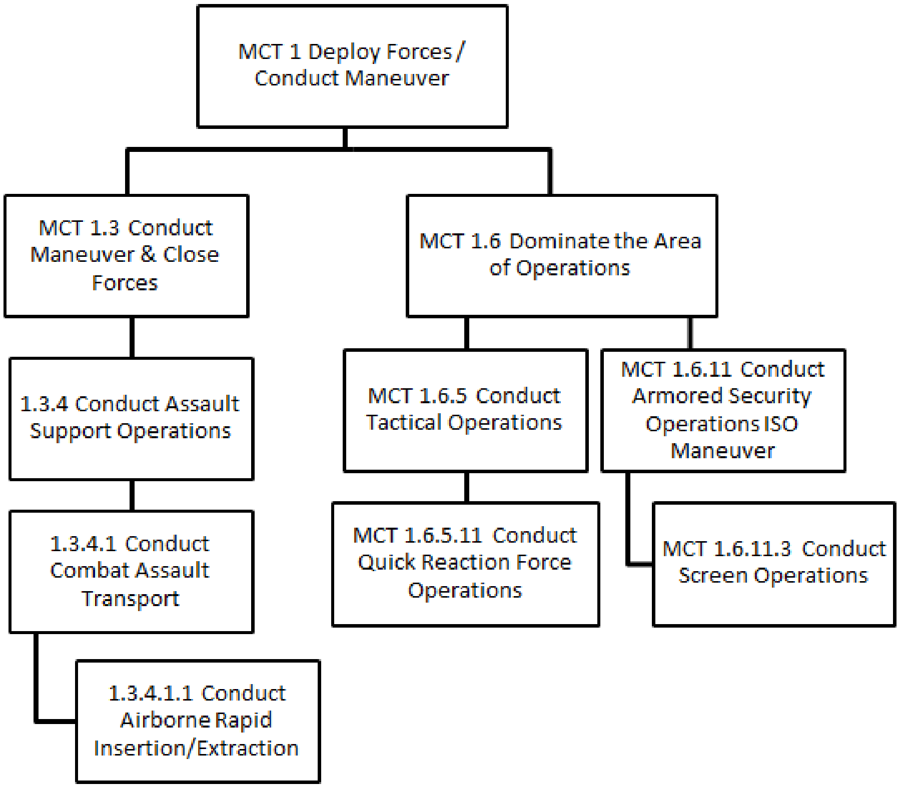


Figure 65. Functional Hierarchy Deploy Forces / Conduct Maneuver

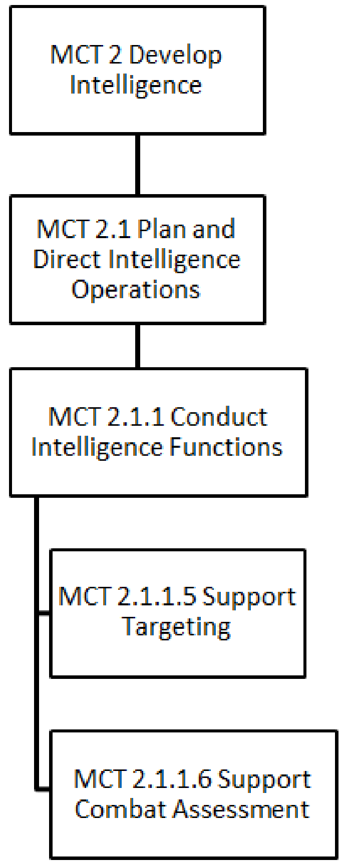


Figure 66. Functional Hierarchy Develop Intelligence

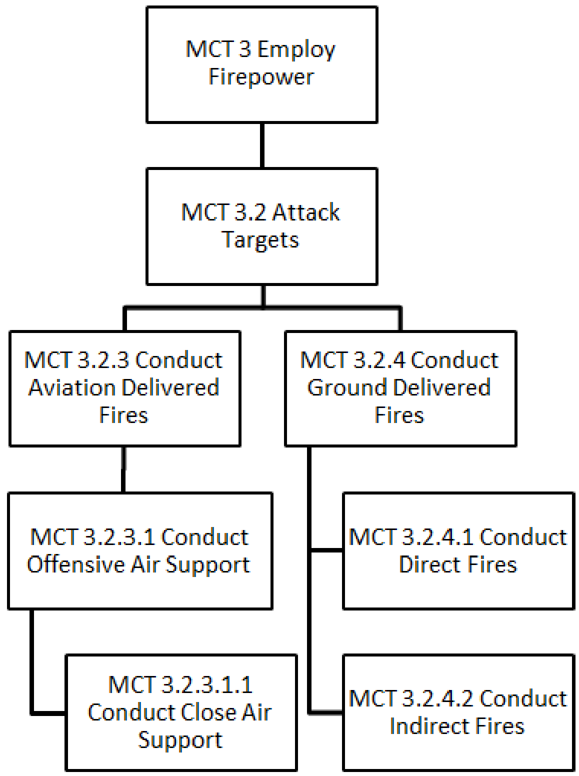


Figure 67. Functional Hierarchy Employ Firepower

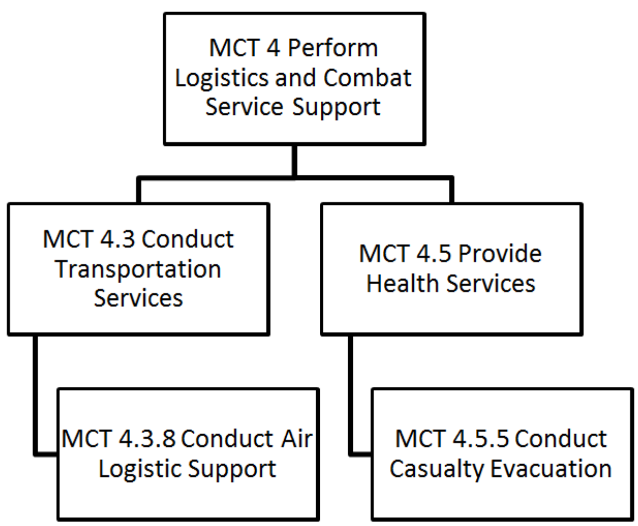


Figure 68. Functional Hierarchy Perform Logistics and Combat Service Support

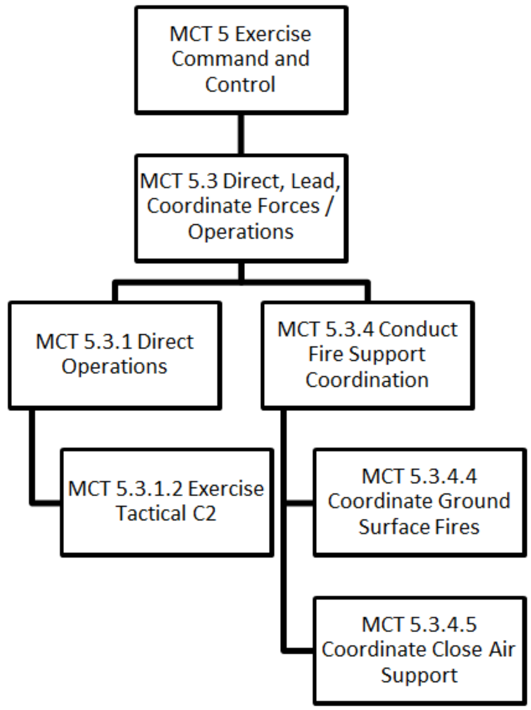


Figure 69. Functional Hierarchy Exercise Command and Control

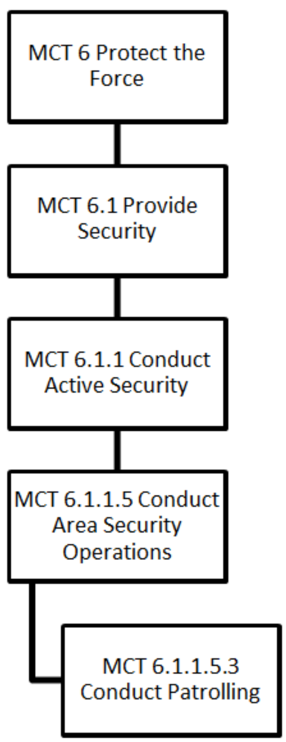


Figure 70. Functional Hierarchy Protect the Force

APPENDIX D: PHYSICAL ARCHITECTURE EQUIPMENT DETAILS

Blue Agent Vehicles

Figure 71. CH-53K (from U.S. Marines.mil 2014)

Table 47. CH-53K Vehicle Specification

	Armor Thickness (mm)	Fuel Consumption Rate (liters / hr)	Range (km)	Fuel Tank Capacity (liters)	Max Speed (km/h)	Capable of Carrying Troops	Capable of Carrying Vehicles	Capable of Being Carried	Max number Troops Carried	Max Vehicles Carried	Max Payload (lbs)
CH-53K	5	2661.14	852	4697.696	315	Yes	Yes	Yes	50	1 HMMWV	35,000

Table 48. CH-53K Weapon Specifications

					Minimum Range		Medium Range		Max Range			
CH-53K	**Weapon Class**	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration (mm)**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius (meters)**
Weapon 1: .50 Cal MG	Primary	200	0.7	21	1.6	1	914.5	0.85	1829	0.75	No	NA
Weapon 2: .50 Cal MG	Primary	200	0.7	21	1.6	1	914.5	0.85	1829	0.75	No	NA
Weapon 3: .50 Cal MG	Primary	200	0.7	21	1.6	1	914.5	0.85	1829	0.75	No	NA

Table 49. CH-53K Sensor Specification

								Sensor Aperture	
	Sensor Name	**Sensor Number**	**Master Enable**	**Sensor Model**	**Enable In this State**	**Detect Range Meters**	**Classify Range (meters)**	**Arc (degrees)**	**Offset (Degrees)**
CH-53K	LR-GMVAS	1	Yes	Simple	Yes	4,828 – 12,875			

Countermeasures:

- AN/APR-39B(V2) – Detects threat and warns crew.
- AN/AAQ-24(V) – Infrared threat detection and modern jamming capabilities.
- AN/ALE-47 –Launches flare and chaff countermeasures.

Figure 72. MV-22 (from Flightglobal/Airspace 2012)

Table 50. MV-22 Vehicle Specification

	Armor Thickness (mm)	Fuel Consumption Rate (liters / hr)	Range (km)	Fuel Tank Capacity (liters)	Max Speed (km/h)	Capable of Carrying Troops	Capable of Carrying Vehicles	Capable of Being Carried	Max number Troops Carried	Max Vehicles Carried	Max Payload (lbs)
MV-22	5	4672.8	722	6513	518	Yes	No	Yes	24	1 HMMWV	15,000

Table 51. MV-22 Weapon Specifications

					Minimum Range		Medium Range		Max Range			
MV-22	**Weapon Class**	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration (mm)**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius (meters)**
Weapon 1: 7.62 GAU-17 Mini Gun	Primary	3000	66.67	6	15	1	546.5	0.85	1093	0.75	No	NA
Weapon 2: Tail mounted .50 Cal MG	Primary	200	0.7	21	1.6	1	914.5	0.85	1829	0.75	No	NA

Table 52. MV-22 Sensor Specification

								Sensor Aperture	
	Sensor Name	**Sensor Number**	**Master Enable**	**Sensor Model**	**Enable In this State**	**Detect Range Meters**	**Classify Range (meters)**	**Arc (degrees)**	**Offset (Degrees)**
MV-22	IDWS	1	Yes	Simple	Yes	8,000	5,000	360	

Countermeasures

- AN/AAR-47 – Missile warning system detects threats and warns crew.
- AN/ALE-47 –Launches flare and chaff countermeasures.

Figure 73. AH-1Z (from Bell Helicopter Textron Inc. 2014)

Table 53. AH-1Z Vehicle Specification

	Armor Thickness (mm)	Fuel Consumption Rate (liters / hr)	Range (km)	Fuel Tank Capacity (liters)	Max Speed (km/h)	Capable of Carrying Troops	Capable of Carrying Vehicles	Capable of Being Carried	Max number Troops Carried	Max Vehicles Carried	Max Payload (lbs)
AH-1Z	5	908.499	685	1561	274	no	No	No	n/a	n/a	n/a

Table 54. AH-1Z Weapon Specifications

					Max Range			
AH-1Z	**Weapon Class**	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration (mm)**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius (meters)**
M197 20 mm cannon	Primary	750	12.167	6.3	2,000	0.75	No	NA
70 mm rockets (hydra 70)	Primary	76	10	9.71	10,500	0.75	No	50
AGM-114A, B, C, F Hellfire guided missiles	Primary	16	0.5	120	8,996.233	0.75	No	20
AIM-9 Sidewinder air-to-air missiles	Primary	6	n/a	5	28,968.2	0.75	No	9

Table 55. AH-1Z Sensor Specifications

								Sensor Aperture	
	Sensor Name	**Sensor Number**	**Master Enable**	**Sensor Model**	**Enable In this State**	**Detect Range Meters**	**Classify Range (meters)**	**Arc (degrees)**	**Offset (Degrees)**
AH-1Z	AN/AAQ-30	1	Yes	Simple	Yes	10,000	8,000	120	

Countermeasures

- AN/APR-39A – Detects threat and warns crew.
- AN/AAR-47 – Interacts with other systems to detect threat and send appropriate warnings.
- AN/AVR-2A – Detects when aircraft is being painted by enemy laser to provide warnings.
- AN/ALE-47 – Launches flare and chaff countermeasures.

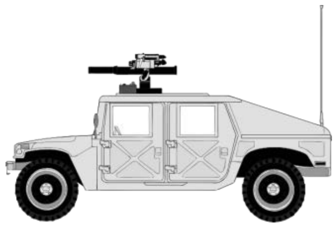


Figure 74. HMMWV (from Vectors4all.net 2013)

Table 56. HMMWV Vehicle Specifications

	Armor Thickness (mm)	Fuel Consumption Rate (liters / hr)	Range (km)	Fuel Tank Capacity (liters)	Max Speed (km/h)	Capable of Carrying Troops	Capable of Carrying Vehicles	Capable of Being Carried	Max Number Troops Carried	Max Vehicles Carried	Max Payload (lbs)
HMMWV	50	19.0	563	95	112.654	Yes	No	Yes	5	0	2313.32

Table 57. HMMWV Weapon Specifications

					Minimum Range		Medium Range		Max Range			
HMMWV	**Weapon Class**	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration (mm)**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius (meters)**
Weapon 1: M2. .50 Cal MG	Primary	200	0.7	21	1.6	1	914.5	0.85	1829	0.75	No	NA
Weapon 2: M240 MG	Primary	200	0.6	8	1.6	1	900	0.85	1800	0.75	No	NA
Weapon 3: M249 MG	Primary	200	1.4	6	0.9	1	500	0.85	100	0.75	No	NA

Figure 75. HMMWV (M997) (from U.S. Federal Goverment 2006)

Table 58. M997 Vehicle Specifications

	Armor Thickness (mm)	Fuel Consumption Rate (liters / hr)	Range (km)	Fuel Tank Capacity (liters)	Max Speed (km/h)	Capable of Carrying Troops	Capable of Carrying Vehicles	Capable of Being Carried	Max number Troops Carried	Max Vehicles Carried	Max Payload (lbs)
M997	50	16.2773	563.2	94.63	88.5139	Yes	No	Yes	4 liters/8 troops	n/a	1920

Blue Agent Personal Equipment

M16 A4

(from U.S. Federal Government 2005)

M249

(from Davric 2007)

M9

(from Benjamin 2007)

Mortar

(from U.S. Federal Government 2010)

M240B

(from U.S. Federal Government 2010)

Figure 76. Blue Agent Weapons

Table 59. Weapon Specifications

					Minimum Range		**Medium Range**		**Max Range**			
	Weapon Class	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration(mm)**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius in meters**
M16 A4	Primary	60	0.2	6	0.9	1	275	0.85	550	0.75	Yes	NA
M249	Primary	200	1.4	6	0.9	1	500	0.85	1000	0.75	Yes	NA
M9	Secondary	30	0.17	3	0.3	1	25	0.85	50	0.75	Yes	NA
Mortar	Primary	10	0.3	60	80	1	2850	0.85	5700	0.75	No	45
M240B	Primary	200	0.6	8	1.6	1	900	0.85	1800	0.75	No	NA

Figure 77. Personal Protection (from U.S. Federal Government 2007)

Table 60. Personal Protection

	Armor Thickness (mm)
IMTV (Improved Modular Tactical Vest)	7

Blue Agent Communications

Figure 78. PRC-152 (from Harris Corporation 2014)

Table 61. PRC-152 System Specifications

	Mobility	JTRS Compliant	Power Requirements	Talk Time per Charge (hr)	Modulation	Range	Antenna	Weight (lbs)
AN/PRC-152	Soldier Carry	Yes	lithium Ion Rechargeable Battery	8	FM, AM, PSK, CPM, FSK	Long Range	Attach to Soldiers gear	2.5

Figure 79. VRC-110 (from Harris Corporation 2014)

Table 62. VRC-110 System Specifications

	Mobility	Antenna	Power Requirements	Range	Output Power (Watts)	Weight (lbs)
AN/VRC-110	HMMWV mount	External (VHF and UHF)	20-32 VDC; 25A	Long Range	50 (30-90 MHz & SATCOM) 20 (90-512 MHz)	23

Blue Agent Optics

Figure 80. PVS-14 (from U.S. Federal Government 2008)

Table 63. PVS-14 System Specifications

	Mobility	Field of View (degrees)	Power Requirements	Use Time per Battery (hrs)	Weight (lbs)
AN/PVS-14	Hands Free	40	1 AA battery	40	.639

Red Agent Vehicles

Figure 81. Land-Rover Defender (from Pathirana 2012)

Table 64. Land-Rover Defender Vehicle Specifications

	Armor Thickness (mm)	Fuel Consumption Rate (liters / (hr)	Range (km)	Fuel Tank Capacity (liters)	Auto Refueler	Max Speed (km/h)	Capable of Being Carried	Max number Troops Carried	Max Payload (lbs)
Land-Rover Defender	5	18.9	570	75	No	144	Yes	5	1300

Table 65. Land-Rover Defender Weapon Specifications

					Minimum Range		Medium Range		Max Range			
Land-Rover Defender	**Weapon Class**	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration (mm)**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius (meters)**
Weapon 1: SPG-9 (73 mm Recoilless Gun)	Primary	1	0.17	400	100	0.85	650	0.75	1300	0.5	Yes	10
Weapon 2: PKM (Russian 7.62mm)	Primary	250	4.17	8	1.2	0.85	500	0.75	1000	0.5	No	NA

Red Agent Personal Gear

(from Special-Ops.org 2012)

(from Sanandros 2008)

(from U.S. Federal Government 1984)

(from Alexxx1979 2012)

Figure 82. Red Agent Weapons

Table 66. Weapon Specifications

					Minimum Range		Medium Range		Max Range			
	Weapon Class	**Shots/ Ammo**	**Shots per Second**	**Armor Penetration (mm)**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per Discharge**	**Range (Meters)**	**Hit Rate per discharge**	**Fire On Closest Targets First**	**Shot Radius in Meters**
MP-444	Secondary	15	0.50	3	0.3	0.85	25	0.75	50	0.5	Yes	NA
AKS-74U	Primary	45	1.67	6	0.9	0.85	200	0.75	400	0.5	Yes	NA
PKM	Primary	250	4.17	8	1.2	0.85	500	0.75	1000	0.5	No	NA
SPG-9	Primary	1	0.17	400	100	0.85	650	0.75	1300	0.5	Yes	10

Figure 83. Personal Protection (from Ironmonger 2010)

Table 67. Personal Protection

	Armor Thickness (mm)
Soft body armor (armor for every red agent)	5

Red Agent Communications

Figure 84. PRC-113 (from MzNobody 2013)

Table 68. PRC-113 System Specification

	Mobility	JTRS Compliant	Power Requirements	Talk Time per Charge (hr)	Modulation	Output Power (Watts)	Range (miles)	Antenna	Weight (lbs)
AN/PRC-113	Man-pack radio	No	BA-5590 lithium battery (15 V 7.5 Ah)	---	AM (VHF 116 – 150 MHz; UHF 225 – 400 MHz)	10	5 – 15	external	16.7

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX E: MANA MODELING SUPPLEMENT

1. MANA Technique Basics

a. Embussing

Embussing is the technique that allows agents to pick up, carry, and drop off other agents, and is useful for insertions and evacuations. The MANA user's manual defines the embussing concept as indicated. The team used embussing extensively. Specifically, embussing was used with respect to the QRF insertion, HMMWV convoy, and enemy Land Rover agent debarking.

> This version of MANA introduces the concept of embussing, where a squad of agents can be carried by another squad until a release trigger point is reached. This feature is most often used to simulate the dismount of troops from a vehicle at a disembarkation point. *(McIntosh et al. 2007)*

b. Situational Awareness and Communications

The MANA user's manual defines SA and Communications as indicated. The use of SA and communications links together allows the sharing of contacts through squad sensing capabilities. The ability to implement specific and group sharing of certain information would have provided the team with the tools to model indirect fires and other C2 sequences to incorporate ACE energy drivers. SA and communications links were not implemented in the current iteration of the model design as indicated in the scoping statement of Chapter IV.D.1.

> Situational Awareness: A collective group memory of perceived enemy contacts. Two types of situational awareness maps are provided in MANA: a squad map which holds direct squad contacts and an inorganic map which stores contacts provided by other squads through communications links. *(McIntosh et al. 2007)*

> Communications: Allows communication of contact sightings between squads. An extensive range of parameters allows issues involving communications links to be thoroughly explored. *(McIntosh et al. 2007)*

c. Fires Execution

The modeling of direct and indirect fires execution via the ACE or GCE is accomplished through sensor observation of enemy positions, or through the passing of observations via SA. MANA defines two types of weapons along with the targeting mode as indicated. The team modeled ground fires based on combinations of agent and squad level SA to allow for the appropriate use of kinetic energy and explosive weapons at the correct agent and squad level. The team limited modeling of both kinetic and explosive weapons to direct ground fires.

> Kinetic Energy weapons are essentially direct fire weapons such as, for example, rifles or machine guns. For these weapons, line-of-fire calculations are carried out between the shooter and enemy agent to see if obstacles or elevated terrain might prevent the agent from being shot. *(McIntosh et al. 2007)*

> High Explosive weapons are intended to represent weapons such as artillery or mortars where no line-of-fire calculation is required and there is a finite blast radius. These weapons especially lend themselves to being queued up through the communications links simulated in MANA. *(McIntosh et al. 2007)*

> Fire Mode/Target: Entities can be targeted based upon agent SA, squad SA, inorganic SA, or both squad and inorganic SA. Agent SA targeting refers to information that the agent owning the weapon gathers directly with its own sensors; only a kinetic energy style weapon is available when Agent SA is selected. The other targeting modes are based upon the situational awareness maps held by that agent's squad; both kinetic energy and high explosive style weapons are available with these targeting modes. *(McIntosh et al. 2007)*

d. Terrain Modeling

Terrain types are used by MANA to affect movement, cover from direct fires weapons, and concealment from observation as indicated in Table 14. Terrain definitions and the manner in which a background map was generated by the team are explained in detail in Chapter IV.D.4. The manner in which terrain impacts were manifested in the simulation was configurable in MANA. The team configured agents such that terrain affects movement, concealment from sensors, and cover from fires. Although terrain affects these components, the team did not configure a movement propensity for the agents to seek particular terrain areas for purposes of movement, cover, or concealment. A personal concealment factor was implemented for counter-detection without regards to terrain effects.

Table 69. MANA Terrain Attribute Definitions (after McIntosh et al. 2007)

Terrain Attribute	Definition
Going	"Going defines how the terrain affects an agent's speed. Possible Going values range from 0.0 to 1.0. A value of 1.0 means the agent can move at its normally defined speed. A value of 0.5 would have the agent moving at half speed, while a value of 0.0 would prevent the agent from moving (McIntosh et al. 2007)."
Cover	"Cover defines the degree to which agents can be shot by direct fire weapons in the terrain. A value of 0.0 means the agent has no cover whatsoever and can be shot as for open terrain. A value 1.0 means the terrain provides full protection from weapons fire (McIntosh et al. 2007)."
Concealment	"Concealment defines the degree to which an agent can be seen in the terrain. A value of 0.0 means the agent is still fully visible while a value of 1.0 means the agent is completely concealed (McIntosh et al. 2007)."

e. Agent Behavioral Modeling and Trigger States

Propensity settings determine the behavior of agents and provide a "rules of engagement" representation. They also allow codifying of escalation and de-escalation in battle engagements. Trigger states provide a means to control the simulation flow by allowing multiple agent behavioral specifications any one of which can be activated at the trigger. The team implemented behavioral settings for movement toward enemies and movement toward waypoints. Trigger states were implemented at the point of enemy observation and in debarking in some cases. The behavioral configuration is embodied in two types of personality weightings as defined by the MANA manual and shown below.

The team did not implement meta-personalities, but the definition is included below for informative purposes.

> The first, personality weightings, determine the automatons' propensity to move towards friendly or enemy entities, towards waypoints or towards easy going or concealed terrain. *(McIntosh et al. 2007)*
>
> The second type, termed move constraints, are meta-personalities which act as conditional modifiers to the basic personality weightings. The three types of move constraint in MANA are (i) Cluster, which "turns off" the automata's propensity to move close to friends above some maximum cluster size, (ii) Advance, which prevents an automaton from moving towards waypoints without a minimum number of friendly units accompanying it, and (iii) Combat, which determines the minimum local numerical advantage a group of automata require before approaching an enemy. These modifiers provide a higher level of behaviour to the agents which might sensibly apply in real battlefield situations. *(McIntosh et al. 2007)*

f. Squad Map

MANA permits the configuration of a base map for each squad. The squad map allowed the team to organize the employment of all agents in accordance with the CONEMP, and establish the general ordered path for agents' movement through waypoints on a per squad basis. This allowed the modeling of a Barra convoy patrol route, QRF insertion path, and enemy squad path configuration around the enemy compound.

2. Squad Activity Maps

The following section contains squad activity maps corresponding to MANA model design in Chapter IV.

Figure 85. HMMWV Convoy Patrol Notional Activity Map

Figure 86. HMMWV Debuss to Battle Notional Activity Map

Figure 87. QRF Insertion Notional Activity Map

Figure 88. QRF Landing to Battle North Notional Activity Map

Figure 89. QRF Landing to Battle South Notional Activity Map

Figure 90. Land Rover Squad Notional Activity Map

Figure 91. Land Rover Squad Debuss to Battle Notional Activity Map

Figure 92. Red Force Ground Squad Activity Map Example A

Figure 93. Red Force Ground Squad Activity Map Example B

Figure 94. Top Level Activity Map – Start

Figure 95. Top Level Activity Map – Mid-HMMWV Patrol

Figure 96. Top Level Activity Map – Mid-QRF Insertion

Figure 97. Top Level Activity Map – Battle Engagement

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX F: MANA OUTPUT FILES STATISTICAL DATA

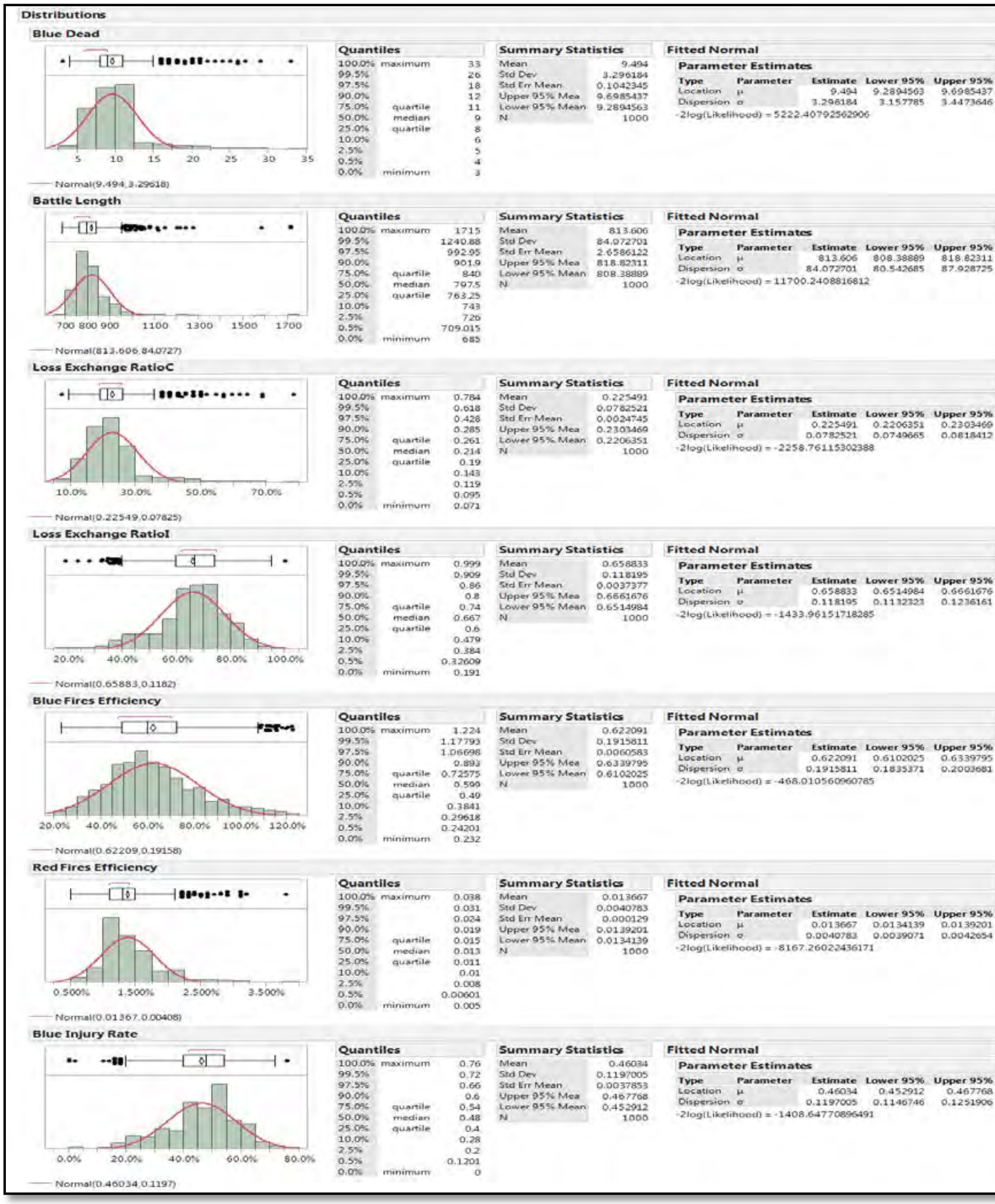


Figure 98. Frequency Distributions and Summary Statistics – 3-Platoon Model (Tool: JMP 11)

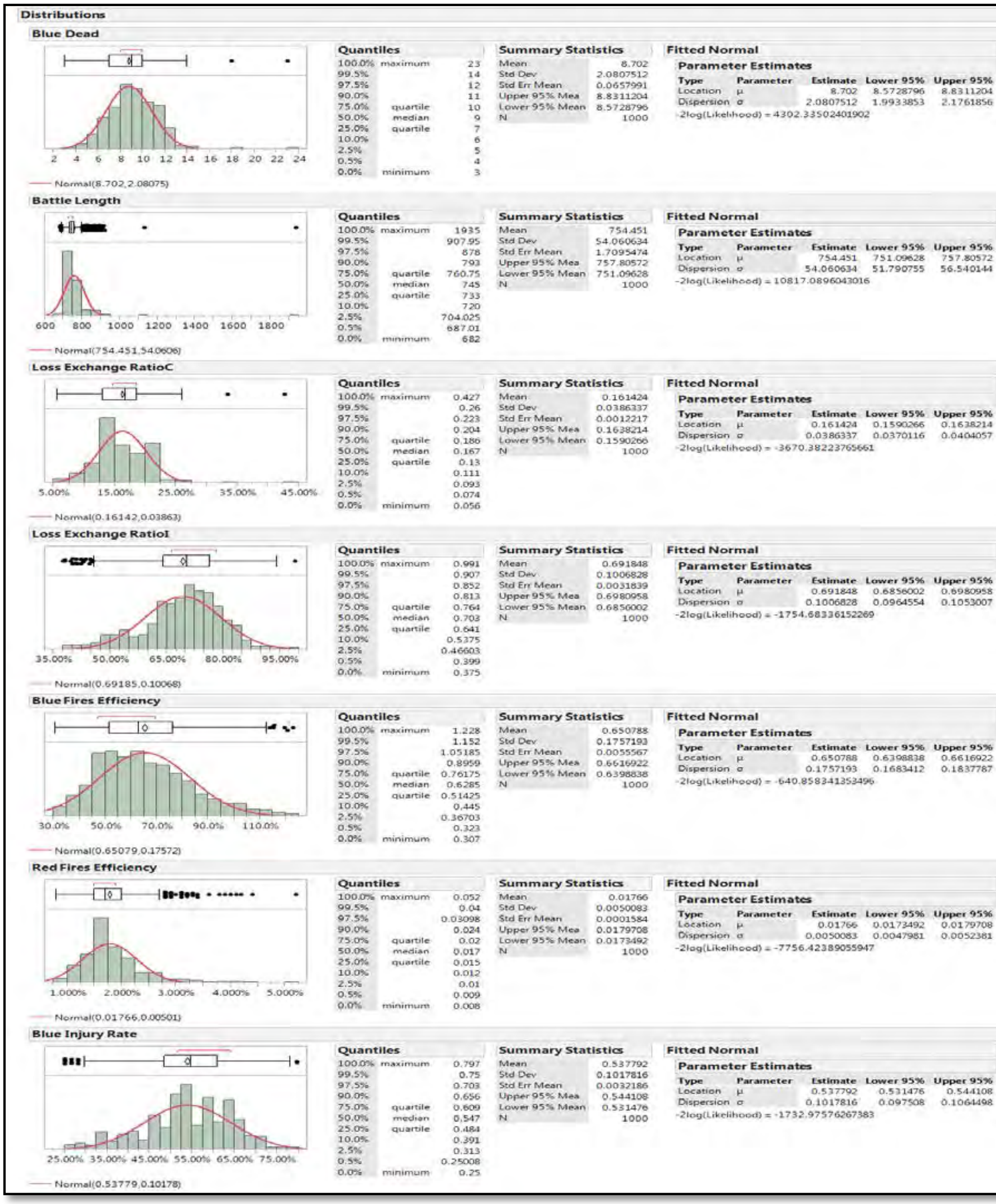


Figure 99. Frequency Distributions and Summary Statistics – 4-Platoon Model (Tool: JMP 11)

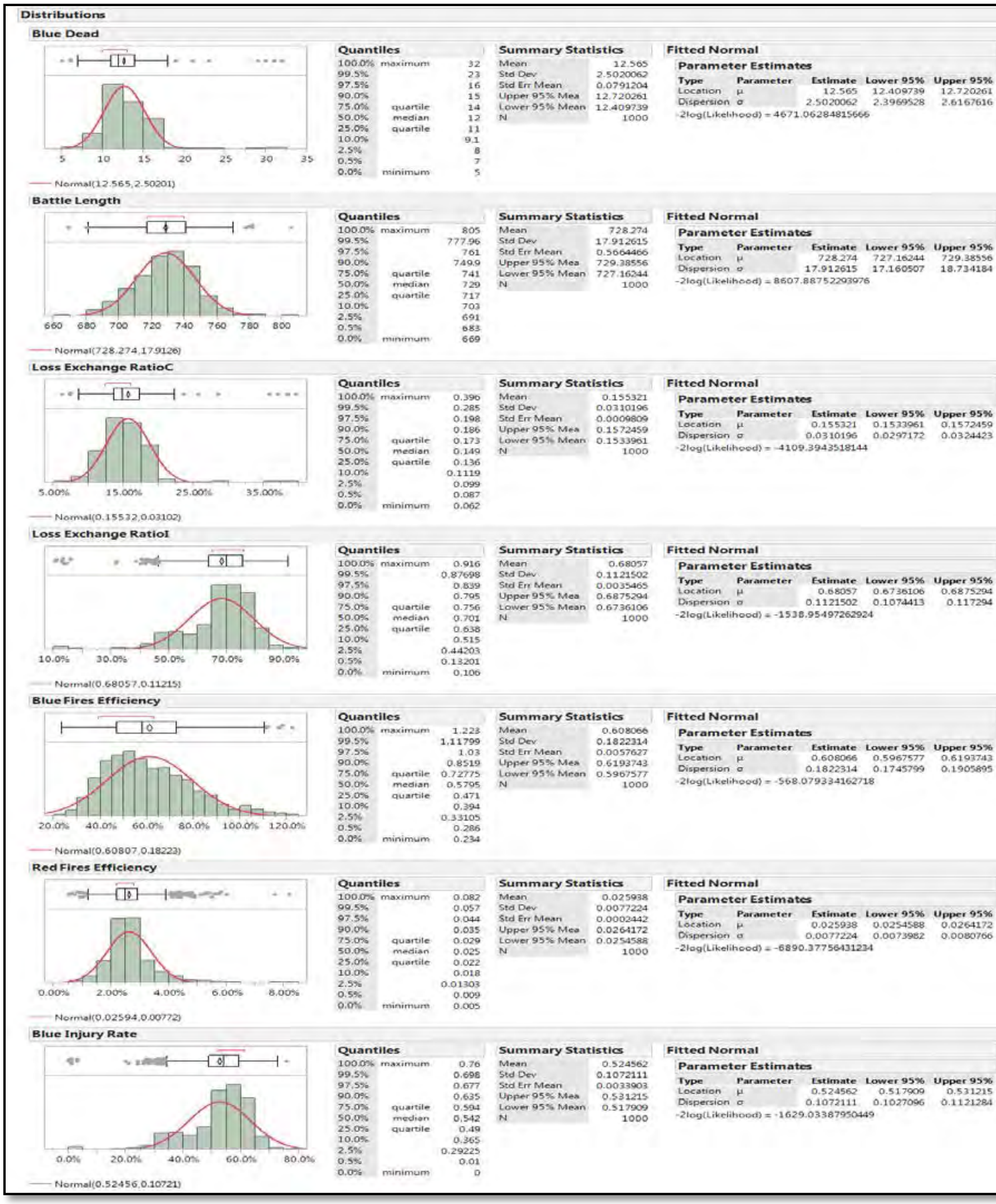


Figure 100. Frequency Distributions and Summary Statistics – 5-Platoon Model (Tool: JMP 11)

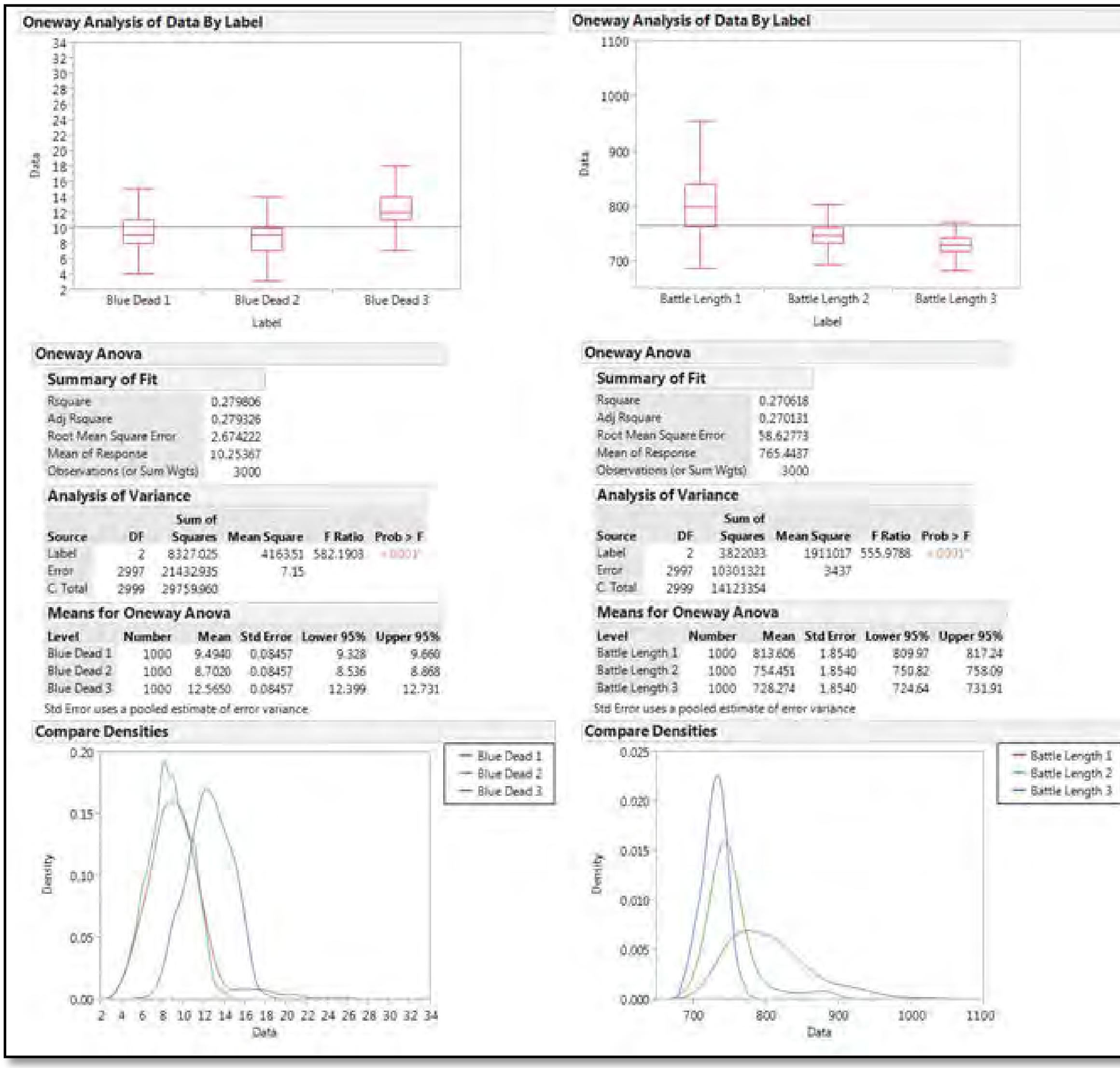


Figure 101. One – Way ANOVA Blue Casualty & Battle Length (Tool: JMP 11)

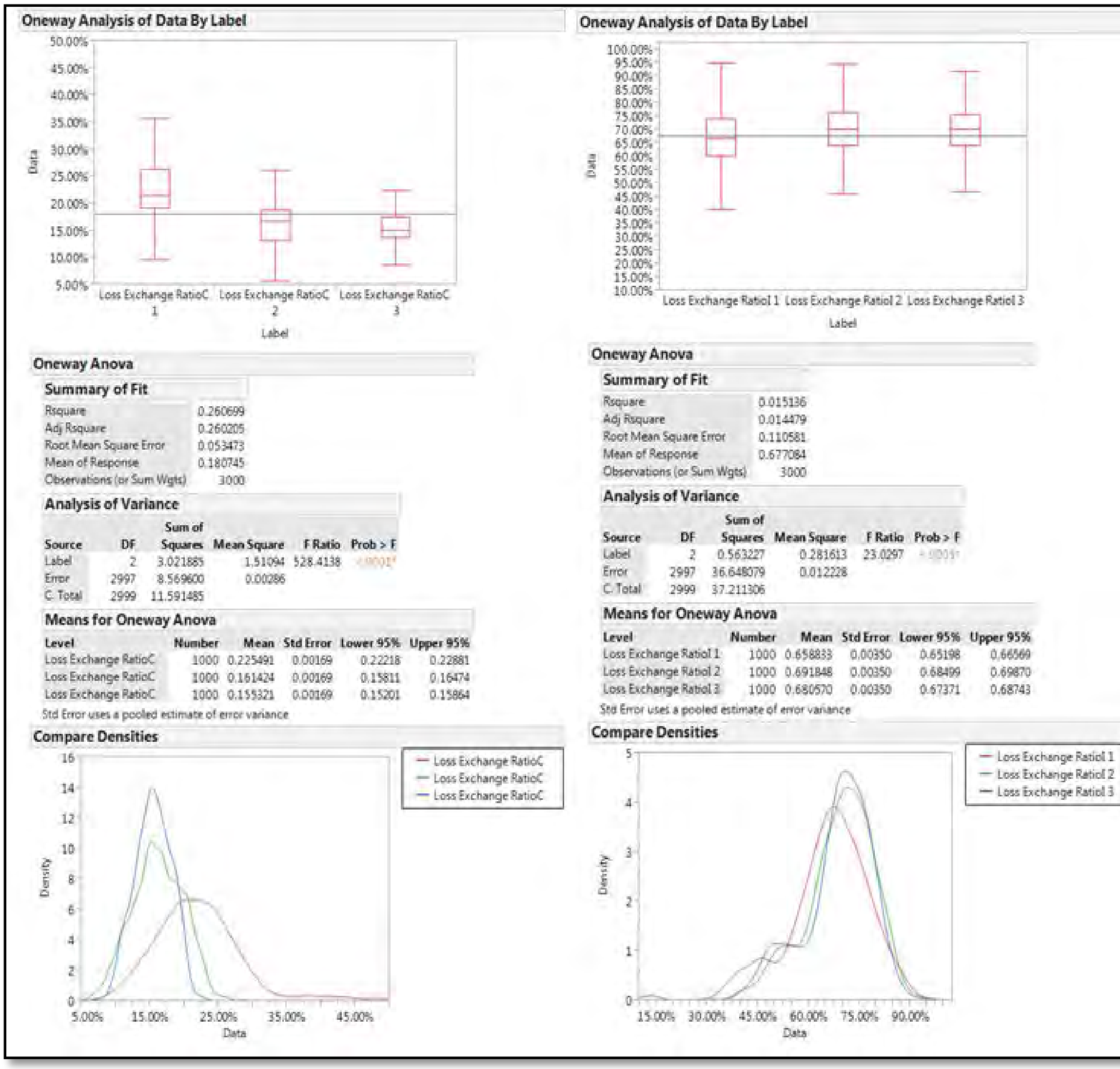


Figure 102. One – Way ANOVA Loss Exchange Ratios (Tool: JMP 11)

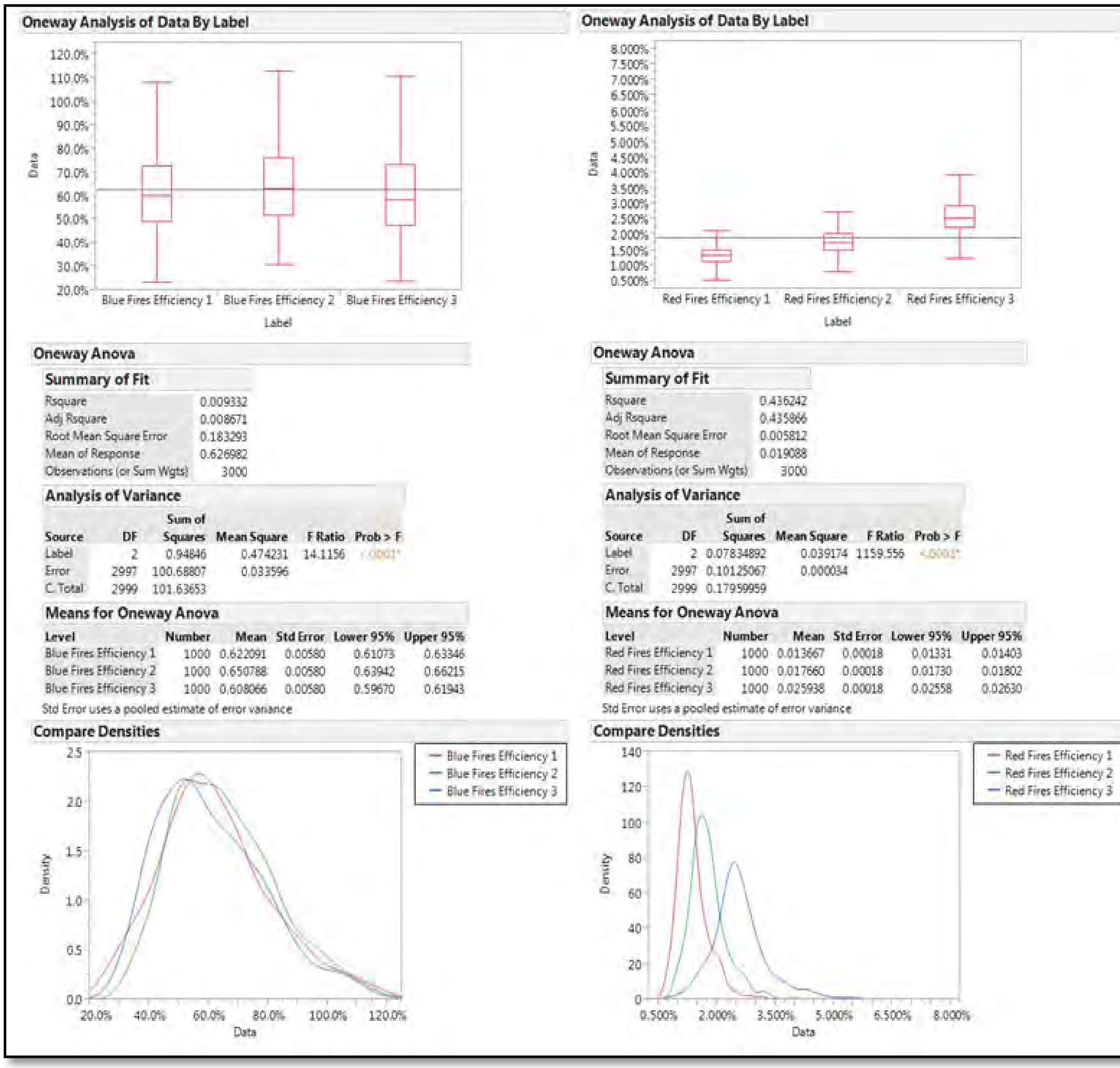
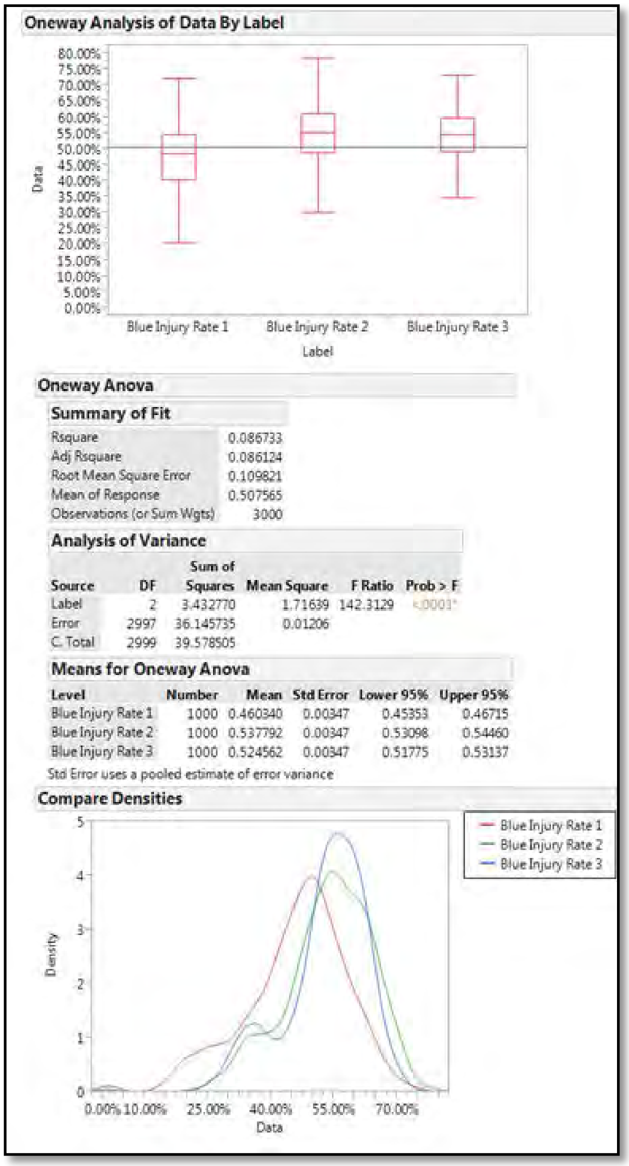


Figure 103. One – Way ANOVA Fires Efficiency (Tool: JMP 11)



Oneway Anova

Summary of Fit

Rsquare	0.086733
Adj Rsquare	0.086124
Root Mean Square Error	0.109821
Mean of Response	0.507565
Observations (or Sum Wgts)	3000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	2	3.432770	1.71639	142.3129	<.0001*
Error	2997	36.145735	0.01206		
C. Total	2999	39.578505			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Blue Injury Rate 1	1000	0.460340	0.00347	0.45353	0.46715
Blue Injury Rate 2	1000	0.537792	0.00347	0.53098	0.54460
Blue Injury Rate 3	1000	0.524562	0.00347	0.51775	0.53137

Std Error uses a pooled estimate of error variance

Figure 104. One – Way ANOVA Blue Injury Rate (Tool: JMP 11)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX G: AHP AND DECISION ANALYSIS DETAIL

The steps detailed in this appendix were used to complete the AHP/MADA method in order to determine stakeholder preference between measures. The process resulted in an OMOE used in the comparison between each of the six MCTs. This process was iterated a total of seven times resulting in seven OMOEs that fed the analysis (Goodwin and Wright 2009).

Measures with inputs of Y/N were assigned the following values to allow for calculation: Y=1, N=0, partially met = 0.5.

1. MCT 3-M1: AHP/MADA Rollup

	Desired Effect	Direction	Value	Model 1	Model 2	Model 3	weight
a.	Loss Exchange C	Low	5	0.225491	0.161424	0.155321	0.55556
b.	Blue Injury Rate	Low	3	0.46034	0.537792	0.524562	0.33333
c.	Blue Fires Efficiency	High	1	0.622091	0.650788	0.608066	0.11111

Step 1:
Each measure is assigned a weighted value by preference, i.e. "Loss Exchange C" is 5x more preferable than "Blue Fires Efficiency"

Step 2:
Empirical data obtained from simulation results when available. (Data used in Step 5 below.)

Measure	a	b	c
a	1	1.667	5
b	0.6	1	3
c	0.2	0.333	1
sum	1.8	3	9

Step 3:
Each measure is weighted against the others to determine a composite score.

Measure	a	b	c	Average
a	0.555556	0.555556	0.555556	0.555556
b	0.333333	0.333333	0.333333	0.333333
c	0.111111	0.111111	0.111111	0.111111

Step 4:
Values are normalized and summed to provide overall weighted average indicating stakeholder preference between measures. Weighted average is used as QFD multiplier in Step 6 below.

Figure 105. MCT 3 – M1: AHP/MADA Process Description: Steps 1–4

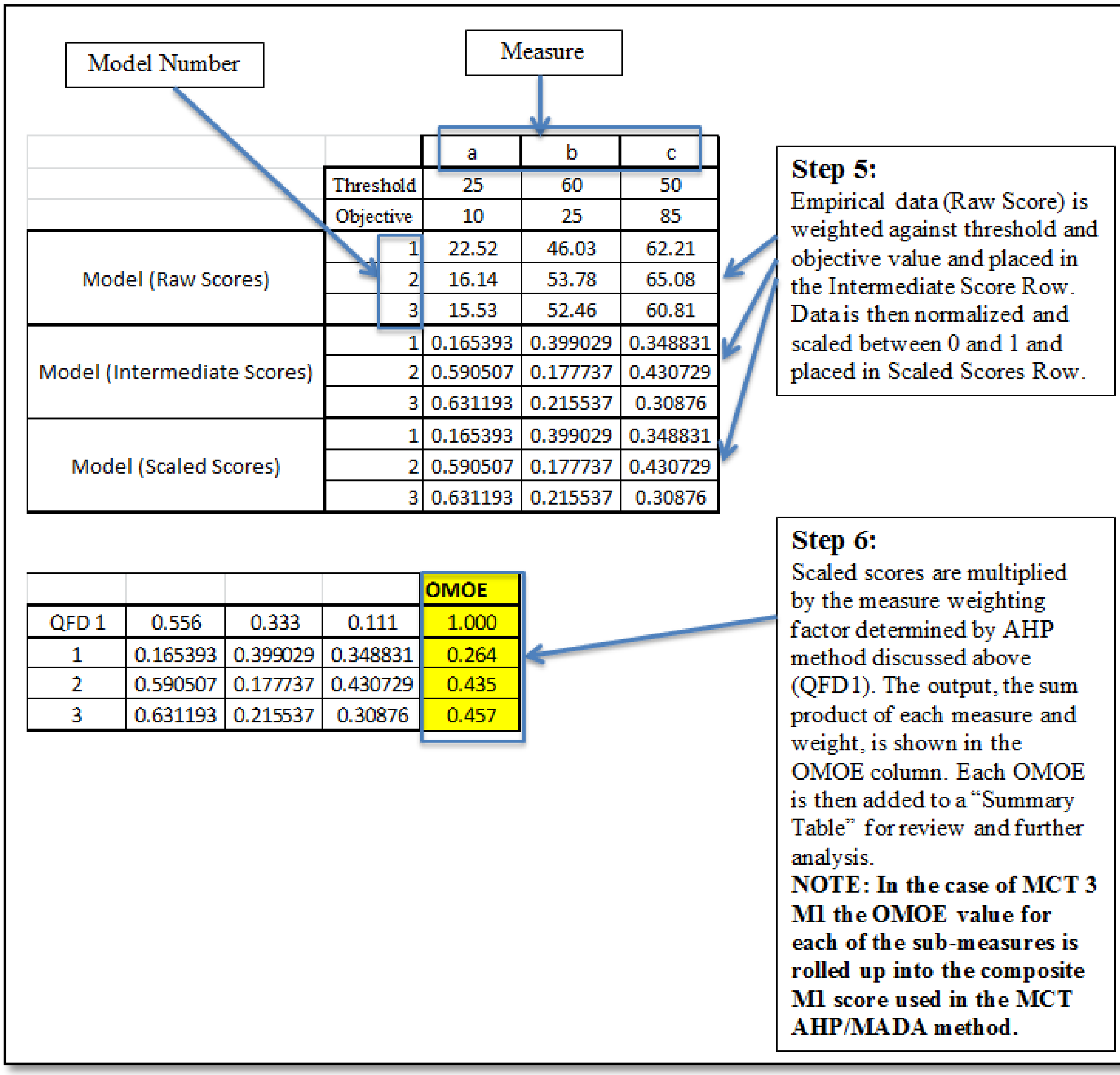


Figure 106. MCT 3 – M1: AHP/MADA Process Description: Steps 5–6

2. MCT 1: AHP/MADA

Table 70. MCT 1: AHP Measure Definition and critical information

MCT 1 Items		Weight	Model 1	Model 2	Model 3
M8	To provide extraction operation.	N (1)	27 min	27 min	27 min
M1	Force required for Quick Reaction Force operations.	N (1)	100%	95.3%	93.8%
M2	Quick Reaction Force reaction time.	Y (2)	15 min	15 min	15 min
M3	Of enemy troops detected before they could come into contact with friendly flanks or rear areas.	N (1)	100%	100%	100%
M4	Of enemy troops detected which were engaged by fire support or maneuver assets before they could come into contact with friendly flanks or rear areas.	N (1)	98.70%	97.40%	96.30%

Table 71. MCT 1: AHP Analysis Part 1

Measure	M8	M1	M2	M3	M4
M8	1	1	0.5	1	1
M1	1	1	0.5	1	1
M2	2	2	1	2	2
M3	1	1	0.5	1	1
M4	1	1	0.5	1	1
Sum	6	6	3	6	6

Table 72. MCT 1: AHP Analysis Part 2

Measure	M8	M1	M2	M3	M4	Average
M8	0.167	0.167	0.167	0.167	0.167	**0.167**
M1	0.167	0.167	0.167	0.167	0.167	**0.167**
M2	0.333	0.333	0.333	0.333	0.333	**0.333**
M3	0.167	0.167	0.167	0.167	0.167	**0.167**
M4	0.167	0.167	0.167	0.167	0.167	**0.167**

Table 73. MCT 1: MADA Measure Definition and Critical Information

MCT 1			Model			
		Data Type	**1**	**2**	**3**	**Weight**
M8	To provide extraction operation.	Analysis	27	27	27	**0.166667**
M1	Force required for Quick Reaction Force operations.	Analysis	100	95.3	93.8	**0.166667**
M2	Quick Reaction Force reaction time.	Analysis	15	15	15	**0.333333**
M3	Of enemy troops detected before they could come into contact with friendly flanks or rear areas.	Analysis	100	100	100	**0.166667**
M4	Of enemy troops detected which were engaged by fire support or maneuver assets before they could come into contact with friendly flanks or rear areas.	Analysis	98.7%	97.4%	96.3%	**0.166667**

Table 74. MCT 1: MADA Part 1

MCT 1		M8	M1	M2	M3	M4
	Threshold	30	100	15	90	95
	Objective	25	75	15	100	100
Model (Raw Scores)	**1**	27	100	15	100	98.7
	2	27	95.3	15	100	97.4
	3	27	93.8	15	100	96.3
Model (Intermediate Scores)	**1**	0.6	0	1	1	0.74
	2	0.6	0.188	1	1	0.48
	3	0.6	0.248	1	1	0.26
Model (Scaled Scores)	**1**	0.6	0	1	1	0.74
	2	0.6	0.188	1	1	0.48
	3	0.6	0.248	1	1	0.26

Table 75. MCT 1: MADA Part 2

						OMOE
QFD 1	0.167	0.167	0.333	0.167	0.167	**1.000**
1	0.6	0	1	1	0.74	**0.723**
2	0.6	0.188	1	1	0.48	**0.711**
3	0.6	0.248	1	1	0.26	**0.685**

3. MCT 2: AHP/MADA

Table 76. MCT 2: AHP Measure Definition and Critical Information

MCT 2 Items		Weight	Model 1	Model 2	Model 3
M1	Targets assigned relative value.	N (1)	N	N	N
M3	Of targets available for striking.	N (1)	100%	100%	100%
M9	Maintain display of current enemy situation with target locations and priorities.	N (1)	Partially met	Partially met	Partially met
M14	Of Blue-on-Blue engagements.	Y (2)	0	0	0
M5	Intelligence capable of being acquired to support Assessment (e.g., COMCAM, Imagery, SIGINT, HUMINT, CA, etc.).	N (1)	Y	Y	Y

Table 77. MCT 2: AHP Analysis Part 1

Measure	M1	M3	M9	M14	M5
M1	1	1	1	0.5	1
M3	1	1	1	0.5	1
M9	1	1	1	0.5	1
M14	2	2	2	1	2
M5	1	1	1	0.5	1
sum	6	6	6	3	6

Table 78. MCT 2: AHP Analysis Part 2

Measure	M1	M3	M9	M14	M5	Average
M1	0.1666667	0.1666667	0.166667	0.166667	0.166667	**0.166667**
M3	0.1666667	0.1666667	0.166667	0.166667	0.166667	**0.166667**
M9	0.1666667	0.1666667	0.166667	0.166667	0.166667	**0.166667**
M14	0.3333333	0.3333333	0.333333	0.333333	0.333333	**0.333333**
M5	0.1666667	0.1666667	0.166667	0.166667	0.166667	**0.166667**

Table 79. MCT 2: MADA Measure Definition and Critical Information

MCT 2			**Model**			
		Data Type	**1**	**2**	**3**	**Weight**
M1	Targets assigned relative value.	Analysis	0	0	0	0.166667
M3	Of targets available for striking.	Analysis	100	100	100	0.166667
M9	Maintain display of current enemy situation with target locations and priorities.	Analysis	0.5	0.5	0.5	0.166667
M14	Of Blue-on-Blue engagements.	Analysis	0	0	0	0.333333
M5	Intelligence capable of being acquired to support Assessment (e.g., COMCAM, Imagery, SIGINT, HUMINT, CA, etc.).	Analysis	1	1	1	0.166667

Table 80. MCT 2: MADA Part 1

MCT 2		M1	M3	M9	M14	M5
	Threshold	0	75	0	3	0
	Objective	1	100	1	0	1
Model (Raw Scores)	**1**	0	100	0.5	0	1
	2	0	100	0.5	0	1
	3	0	100	0.5	0	1
Model (Intermediate Scores)	**1**	0	1	0.5	1	1
	2	0	1	0.5	1	1
	3	0	1	0.5	1	1
Model (Scaled Scores)	**1**	0	1	0.5	1	1
	2	0	1	0.5	1	1
	3	0	1	0.5	1	1

Table 81. MCT 2: MADA Part 2

						OMOE
QFD 1	0.167	0.167	0.167	0.333	0.167	**1.000**
1	0	1	0.5	1	1	**0.750**
2	0	1	0.5	1	1	**0.667**
3	0	1	0.5	1	1	**0.667**

4. MCT 3: AHP/MADA

Table 82. MCT 3: AHP Measure Definition and Critical Analysis

MCT 3 Items		Weight	Model 1	Model 2	Model 3
M4	Of sorties daily sustained during contingency/combat operations.	N (1)	1	1	1
M1	Of targets attacked with desired effects.	Y (5)	0.2637	0.4352	0.4568
M5	Take the enemy under fire using lethal and nonlethal gunfire delivered on target.	N (1)	Y	Y	Y
M6	Of missions completed.	N (1)	1	1	1

Table 83. MCT 3: AHP Analysis Part 1

Measure	M4	M1	M5	M6
M4	1	0.2	1	1
M1	5	1	5	5
M5	1	0.2	1	1
M6	1	0.2	1	1
sum	8	1.6	8	8

Table 84. MCT 3: AHP Analysis Part 2

Measure	M4	M1	M5	M6	Average
M4	0.125	0.125	0.125	0.125	**0.125**
M1	0.625	0.625	0.625	0.625	**0.625**
M5	0.125	0.125	0.125	0.125	**0.125**
M6	0.125	0.125	0.125	0.125	**0.125**

Table 85. MCT 3: MADA Measure Definition and Critical Information

MCT 3			Model			
		Data Type	**1**	**2**	**3**	**Weight**
M4	Of sorties daily sustained during contingency/combat operations.	Analysis	1	1	1	**0.125**
M1	Of targets attacked with desired effects.	Experimental				**0.625**
M5	Take the enemy under fire using lethal and nonlethal gunfire delivered on target.	Experimental	1	1	1	**0.125**
M6	Of missions completed.	Experimental	1	1	1	**0.125**

Table 86. MCT 3: MADA Part 1

MCT 3		M4	M1	M5	M6
	Threshold	1	16	0	1
	Objective	2	46	1	2
Model (Raw Scores)	1	1	26.4	1	1
	2	1	43.5	1	1
	3	1	45.7	1	1
Model (Intermediate Scores)	1	0	0.346667	1	0
	2	0	0.916667	1	0
	3	0	0.99	1	0
Model (Scaled Scores)	1	0	0.346667	1	0
	2	0	0.916667	1	0
	3	0	0.99	1	0

Table 87. MCT 3: MADA Part 2

					OMOE
QFD 1	0.125	0.625	0.125	0.125	**1.000**
1	0	0.346667	1	0	**0.342**
2	0	0.916667	1	0	**0.698**
3	0	0.99	1	0	**0.744**

5. MCT 4: AHP/MADA

Table 88. MCT 4: AHP Measure Identification and Critical Information

MCT 4 Items		**Weight**	**Model 1**	**Model 2**	**Model 3**
M5	Of sorties daily sustained during contingency/combat operations.	N (1)	1	1	1
M8	Of required support material distributed at the time and place required.	N (1)	100%	100%	100%
M6	From wound or injury until person is in surgery or other appropriate care.	Y (2)	.92 hours	.92 hours	1 hours

Table 89. MCT 4: AHP Analysis Part 1

Measure	**M5**	**M8**	**M6**
M5	1	1	0.5
M8	1	1	0.5
M6	2	2	1
sum	4	4	2

Table 90. MCT 4: AHP Analysis Part 2

Measure	**M5**	**M8**	**M6**	**Average**
M5	0.25	0.25	0.25	**0.25**
M8	0.25	0.25	0.25	**0.25**
M6	0.5	0.5	0.5	**0.5**

Table 91. MCT 4: MADA Measure Definition and Critical Information

MCT 4			Model			
		Data Type	**1**	**2**	**3**	**Weight**
M5	Of sorties daily sustained during contingency/combat operations.	Analysis	1	1	1	**0.25**
M8	Of required support material distributed at the time and place required.	Analysis	100	100	100	**0.25**
M6	From wound or injury until person is in surgery or other appropriate care.	Analysis	0.92	0.92	1	**0.5**

Table 92. MCT 4: MADA Part 1

MCT 4		**M5**	**M8**	**M6**
	Threshold	0	90	2
	Objective	1	100	1
Model (Raw Scores)	**1**	1	100	0.92
	2	1	100	0.92
	3	1	100	1
Model (Intermediate Scores)	**1**	1	1	1.08
	2	1	1	1.08
	3	1	1	1
Model (Scaled Scores)	**1**	1	1	1
	2	1	1	1
	3	1	1	1

Table 93. MCT 4: MADA Part 2

				OMOE
QFD 1	0.250	0.250	0.500	**1.000**
1	1	1	1	**1.000**
2	1	1	1	**1.000**
3	1	1	1	**1.000**

6. MCT 5: AHP/MADA

Table 94. MCT 5: AHP Measure Definition and Critical Information

MCT 5 Items		Weight	Model 1	Model 2	Model 3
M3	Of units responding appropriately to orders.	N (1)	100%	100%	100%
M1	Of targets successfully engaged.	Y (2)	98.70%	97.40%	96.30%
M8	Of on-station time of CAS support.	Y (2)	53 min	52 min	54 min

Table 95. MCT 5: AHP Analysis Part 1

Measure	M3	M1	M8
M3	1	0.5	0.5
M1	2	1	1
M8	2	1	1
sum	5	2.5	2.5

Table 96. MCT 5: AHP Analysis Part 2

Measure	M3	M1	M8	Average
M3	0.2	0.2	0.2	**0.2**
M1	0.4	0.4	0.4	**0.4**
M8	0.4	0.4	0.4	**0.4**

Table 97. MCT 5: MADA Measure Definition and Critical Information

MCT 5			Model			
		Data Type	**1**	**2**	**3**	**Weight**
M3	Of units responding appropriately to orders.	Analysis	100	100	100	**0.2**
M1	Of targets successfully engaged.	Analysis	98.7	97.4	96.3	**0.4**
M8	Of on-station time of CAS support.	Analysis	53	52	54	**0.4**

Table 98. MCT 5: MADA Part 1

MCT 5		**M3**	**M1**	**M8**
	Threshold	95	90	60
	Objective	100	100	30
Model (Raw Scores)	**1**	100	98.7	53
	2	100	97.4	52
	3	100	96.3	54
Model (Intermediate Scores)	**1**	1	0.87	0.233333
	2	1	0.74	0.266667
	3	1	0.63	0.2
Model (Scaled Scores)	**1**	1	0.87	0.233333
	2	1	0.74	0.266667
	3	1	0.63	0.2

Table 99. MCT 5: MADA Part 2

				OMOE
QFD 1	0.200	0.400	0.400	**1.000**
1	1	0.87	0.233333	**0.641**
2	1	0.74	0.266667	**0.603**
3	1	0.63	0.2	**0.532**

7. MCT 6: AHP/MADA

Table 100. MCT 6: AHP Measure Definition and Critical Information

MCT 6 Items		Weight	Model 1	Model 2	Model 3
M1	Of friendly operations degraded due to enemy observation, detection, interference, espionage, terrorism and/or sabotage.	N (1)	1	1	1
M2	By enemy troops, or partisans, affecting security of force and means in the operations area.	N (1)	1	1	1
M9	Urban patrolling conducted.	Y (2)	Y	Y	Y

Table 101. MCT 6: AHP Analysis Part 1

Measure	M1	M2	M9
M1	1	1	0.5
M2	1	1	0.5
M9	2	2	1
sum	4	4	2

Table 102. MCT 6: AHP Analysis Part 2

Measure	M1	M2	M9	Average
M1	0.25	0.25	0.25	**0.25**
M2	0.25	0.25	0.25	**0.25**
M9	0.5	0.5	0.5	**0.5**

Table 103. MCT 6: MADA Measure Definition and Critical Information

MCT 6			Model			
		Data Type	**1**	**2**	**3**	**Weight**
M1	Of friendly operations degraded due to enemy observation, detection, interference, espionage, terrorism and/or sabotage.	Analysis	1	1	1	**0.25**
M2	By enemy troops, or partisans, affecting security of force and means in the operations area.	Analysis	1	1	1	**0.25**
M9	Urban patrolling conducted.	Analysis	1	1	1	**0.5**

Table 104. MCT 6: MADA Part 1

MCT 6		M1	M2	M9
	Threshold	1	1	0
	Objective	0	0	1
Model (Raw Scores)	**1**	1	1	1
	2	1	1	1
	3	1	1	1
Model (Intermediate Scores)	**1**	0	0	1
	2	0	0	1
	3	0	0	1
Model (Scaled Scores)	**1**	0	0	1
	2	0	0	1
	3	0	0	1

Table 105. MCT 6: MADA Part 2

				OMOE
QFD 1	0.250	0.250	0.500	**1.000**
1	0	0	1	**0.500**
2	0	0	1	**0.500**
3	0	0	1	**0.500**

Table 106. MCT 1–6: AHP/MADA Analysis Results Table

	MCT 1	MCT 2	MCT 3	MCT 4	MCT 5	MCT 6	
Weight	**0.1**	**0.1**	**0.5**	**0.1**	**0.1**	**0.1**	**OMOE**
Model 1	0.723	0.750	0.342	1.000	0.641	0.500	**0.53230**
Model 2	0.711	0.667	0.698	1.000	0.603	0.500	**0.69703**
Model 3	0.685	0.667	0.744	1.000	0.532	0.500	**0.71021**

The summary provided a composite look at all of the OMOEs generated during the process. The weights in this table were given on the basis of an overall comparison of each MCT in order to plot the efficient frontier.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Abbasi, Farrukh. 2014. "Top 10 Attack Helicopters." Last modified July 27. http://www.neozinfo.com/2014/07/top-10-attack-helicopters.html.

Aircav. 2008. "Ammunition 20-Millimeter." Last modified January 12. http://www.aircav.com/cobra/ammo20.html.

———. 2008. "The M197 20mm Automatic Gun." Last modified January 12. http://www.aircav.com/cobra/m197.html

Alexxx1979. 2012. *Wikimedia Commons.* Last modified May 08. http://commons.wikimedia.org/wiki/File:Balaklava_Naval_museum_complex_Recoilless_rifle_SPG-9_IMG_1074_1725.jpg.

AM General. 2014. "A2 Series Components." Last modified 2014. http://www.amgeneral.com/vehicles/hmmwv/a2-series/components.

———. 2010. "M115A1 HMMWV." Last modified August 19. http://www.amgeneral.com/files/specs-sheet-m1152-domestic-04-10.pdf.

ASU, Inc. 2014. *Aviation Specialties Unlimited.* Last modified 2014. http://www.asu-nvg.com/products/product_by_type/night_vision_goggles/?ProductID=172.

ATK Integrated Systems. 2000. "AN/AAR-47(V)2." *www.sea-specialmissions.com.* Last modified January 28. http://www.sea-specialmissions.com/brochures/AAR-47(V)2%20Data%20Sheet.pdf.

Automobile-catalog.com. 2014. "Land-Rover Timeline." *www.automobile-catalog.com.* Last modified 2014. http://www.automobile-catalog.com/timeline-land-rover.html.

BAE Systems. 2014. "Remote Guardian System - BAE Systems." BAE Systems. Last modified 2014. http://www.baesystems.com/product/BAES_020215/remote-guardian-system.

Bahm, MAJ Eric M., MAJ Amy Bateman, MAJ Joshua Berry, MAJ Owen Bishop, LTC Thomas Bogar, Lt Col Helen Bowman, MAJ John Cheery, MAJ Jason De Son, Doug Dribben, MAJ Jessica Farrell, MAJ Matthew Festa, MAJ Johnny Fields, LTC Benjamin Grimes, MAJ Ryan Howard, LTC William Johnson, MAK Ryan Leary, LCDR David Lee, MAJ Matthew Lund, LTC William Mullee, LTC Joseph Mackey, MAJ Dale McFeatters, LTC Andrew McKee, MAJ Kristy Radio, MAJ Scott T. Randall, CDR David Sherry, MAJ Dan Stigall, MAJ Joshua Van Eaton, MAJ Patrick Walsh. 2014. *Operational Law Handbook.* Charlottesville, Virginia:

International and Operational Law Department, The Judge Advocate General's Legal Center & School. http://www.loc.gov/rr/frd/Military_Law/pdf/operational-law-handbook_2014.pdf.

Barton, Russell R. 2004. "Designing Simulation Experiments." *informs-sim.org.* http://informs-sim.org/wsc04papers/010.pdf.

Bell Helicopter. 2004. *AH-1Y Pocket Guide.* Fort Worth, Texas: Bell Helicopter Textron Inc.

———. 2014. "The Bell AH-1Z Zulu." Bell Helicopter. Last modified 2014. http://www.bellhelicopter.com/Military/BellAH-1Z/1291148375494.html#/?tab=highlights-tab.

Benjamin, Peter. 2007. *Wikimedia Commons.* Last modified August 13. http://commons.wikimedia.org/wiki/File:Beretta_92_FS.gif.

Besser, James, Jamesia Hobbs, Kevin Hovis, Dominic Hunter, Bruce Leaman, Joseph McPherson, John Pomfret, and Erin Valliere. 2013. "Expeditionary Energy Efficiency in Support of Foreign Humanitarian Aid/Disaster Relief." Capstone Report, Naval Postgraduate School.

Boeing. 2014. "AGM-114 Hellfire Missile." Boeing. Last modified 2014. http://www.boeing.com/boeing/history/bna/hellfire.page.

———. 2014. "V-22 Osprey Technical Specs." Last modified October 17. http://www.boeing.com/boeing/rotorcraft/military/v22/v22spec.page.

Buede, Dennis M. 2009. *The Engineering Design of Systems Models and Methods.* Hoboken, NJ: John Wiley & Sons.

Cooke, Gary W. 2004. ."50 Caliber Browning (12.7 x 99mm) Ammunition." Gary's U.S. Infantry Weapons Reference Guide. Last modified November 14. http://www.inetres.com/gp/military/infantry/mg/50_ammo.html.

Crowell, Jeff. 2013. "SailorSpeak." A Glossary of Military Terminology, Jargon, and Slang. Last modified May 07. http://www.combat.ws/S4/SAILOR/SAILOR.HTM.

Darilek, Richard E., Walter L. Perry, Jerome Bracken, John IV Gordon, and Brian Nichiporuk. 2001. *Measures of Effectiveness for the Information-Age Army.* Santa Monica, CA: Rand.

Davric. 2007. *Wikimedia Commons.* Last modified September 09. http://commons.wikimedia.org/wiki/File:Minimi.jpg.

Defense Industry Daily Staff. 2012. "BAE's Turret to Deploy in CV-22s, MV-22s." *Defense Industry Daily*. Last modified April 25. http://www.defenseindustrydaily.com/baes-turret-to-trial-in-cv-22s-04618/.

———. 2005. "L-3 Titan Upgrading LCACs." *Defense Industry Daily*. Last modified May 24. http://www.defenseindustrydaily.com/l3-titan-upgrading-lcacs-01530/.

DefenseTalk. 2005. "AN/AAQ-29A Forward Looking Infrared (FLIR) CH-53E helicopters." Defense Talk. Last modified September 15. http://www.defencetalk.com/anaaq-29a-forward-looking-infrared-flir-ch-53e-helicopters-3331/.

Donaldson Company Inc. 2014. "Press Release: Aircraft." Donaldson Filtration Solutions. Last modified May 5. http://www.emea.donaldson.com/en/aircraft/news/084767.html.

Driscoll, Patrick J., and Paul Kucik. 2011. "System Life Cycle." In *Decision Making in Systems Engineering and Management*, by Gregory S. Parnell, Patrick J. Driscoll and Dale L. Henderson, 65–94. Hoboken, NJ: John Wiley & Sons, Inc.

EnemyForces.net. 2012. "Assault Rifle AKS-74U." EnemyForces. Last modified 2012. http://www.enemyforces.net/firearms/aks74u.htm.

———. 2012. "Self Loading Pistol MP-444 Bagira." EnemyForces. Last modified 2012. http://www.enemyforces.net/firearms/bagira.htm.

FAS.org. 1999. "M252 81mm Medium Extended Range Mortar." Military Analysis Network. Last modified January 05. http://fas.org/man/dod-101/sys/land/m252.htm.

———. 1999. "LSD-41 Whidbey Island Class." Military Analysis Network. Last modified November 26. http://fas.org/man/dod-101/sys/ship/lsd-41.htm.

———. 2000. "AN/AVR-2 Laser Warning System." Military Analysis Network. Last modified February 10. http://fas.org/man/dod-101/sys/ac/equip/an-avr-2.htm.

———. 2000. "AN/APR-39 Radar Warning Receiver (RWR)." Military Analysis Network. Last modified February 10. http://fas.org/man/dod-101/sys/ac/equip/an-apr-39.htm.

———. 2000. "High Mobility Multipurpose Wheeled Vehicle (HMMWV) (M998 Truck)." Military Analysis Network. Last Modified May 04. http://fas.org/man/dod-101/sys/land/m998.htm.

———. 2000. "Hydra-70 Rocket System." Military Analysis Network. Last modified May 05. http://fas.org/man/dod-101/sys/missile/hydra-70.htm.

Find The Best. 2014. “Sikorsky CH-53K.” FindTheBest. Last modified 2014. http://helicopters.findthebest.com/l/18/Sikorsky-CH-53K.

Flightglobal/Airspace. 2012. “MV-22 Osprey Warms up for Farnborough.” *Flightgobal*. Last modified July 6. http://www.flightglobal.com/blogs/aircraft-pictures/2012/07/mv-22-osprey-warms-up-for-farn/.

Foorsberg, Kevin, and Howard Cotterman. 2005. *Visualizing Project Management: Models and Frameworks for Mastering Complex Systems*. Hoboken, NJ: John Wiley & Sons, Inc.

Global Security. 2014. “3rd Battalion, 6th Marines.” GlobalSecurity.org. Last modified 2014. http://www.globalsecurity.org/military/agency/usmc/3-6.htm.

———. 2014. “Logistics Vehicle System Replacement (LVSR).” GlobalSecurity.org. Last modified 2014. http://www.globalsecurity.org/military/systems/ground/lvsr.htm.

Geoffrey, Norman R., and David L. Steiner. 2003. *PDQ Pretty Darned Quick Statistics*. Shelton, CT: People’s Medical Publishing House.

Goodwin, Paul, and George Wright. 2009. *Decision Analysis for Management Judgment*. West Sussex, UK: John Wiley & Sons Ltd.

Google Maps. 2014. “Dakar, Senegal to Kaolack, Senegal.” Accessed August 16. https://www.google.com/maps/dir/Dakar,+Senegal/14.1388013,-16.0785855/@14.3189685,-17.1668945,245317m/data=!3m1!1e3!4m9!4m8!1m5!1m1!1s0xec172f5b3c5bb71:0xb17c17d92d5db21f!2m2!1d-17.3660286!2d14.7645042!1m0!3e0.

———. 2014. “Touba, Senegal to Barra, The Gambia.” Accessed August 09. https://www.google.com/maps/dir/Touba,+Senegal/Dakar,+Senegal/@14.5747366,-16.3070365,9z/data=!4m14!4m13!1m5!1m1!1s0xeea49f65451438f:0x93694258df5b916a!2m2!1d-15.883333!2d14.866667!1m5!1m1!1s0xec172f5b3c5bb71:0xb17c17d92d5db21f!2m2!1d-17.3660286!2d14.7645.

———. 2014. “Kaolack, Senegal to Barra, The Gambia.” Accessed August 09. https://www.google.com/maps/dir/Barra,+The+Gambia/14.1371173,-16.0665922/@13.7001474,-16.6227224,9z/data=!4m9!4m8!1m5!1m1!1s0xec29d84e84ffd89:0xcda461efa7c2ada6!2m2!1d-16.5451491!2d13.4865118!1m0!3e0.

Harris Corporation. 2010. “AN/PRC-152(C)/AN/VRC-110 Applications and Accessory Handbook.” Harris. Last modified 2010. http://rf.harris.com/media/prc-152_vrc-110_handbook_tcm26-11408.pdf.

———. 2014. “AN/PRC-152A Wideband Networking Radio” Harris. Last modified 2014. http://rf.harris.com/capabilities/tactical-radios-networking/an-prc-152a.asp.

———. 2014. “AN/VRC-110 Multiband Vehicular Radio System.” Harris. Last modified 2014. http://rf.harris.com/capabilities/tactical-radios-networking/an-prc-152/an-vrc-110.asp.

International Council on Systems Engineering (INCOSE). 2007. “Systems Engineering Vision 2020.” www.incose.org. Last modified September. http://www.incose.org/ProductsPubs/pdf/SEVision2020_20071003_v2_03.pdf.

Ironmonger. 2010. *Wikimedia Commons.* Last modified January 15. http://commons.wikimedia.org/wiki/File:M55_2.JPG.

Kable. 2014. “AH-1W/AH-1Z Super Cobra Attack Helicopter.” army-technology.com. Last modified 2014. http://www.army-technology.com/projects/supcobra/.

Kusiak, Andrew. 2005. “Data Farming: A Primer.” *International Journal of Operations Research* II (2005): 48–57.

Lange, CPT Adam W. 1998. “Hellfire.” FAS. Last modified February. http://fas.org/man/dod-101/sys/missile/docs/1helfire.pdf.

Lauren, M.K., J.M. Smith, J. Moffat, and N.D. Perry. 2005. *Using The Fractal Attrition Equation to Construct a Metamodel of the MANA Cellular Automaton Combat Model.* The Technical Cooperation Program.

Law, Averill M. 2007. *Simulation Modeling and Analysis 4th Edition.* New York, NY: McGraw Hill.

Lockheed Martin. 2014. “TSS.” Lockheed Martin. Last modified 2014. http://www.lockheedmartin.com/us/products/TSS.html.

Macal, Charles M., and Michael J. North. 2006. “Introduction to Agent-based Modeling and Simulation.” Argonne National Laboratory. Last modified November 29. http://www.mcs.anl.gov/~leyffer/listn/slides-06/MacalNorth.pdf.

Maier, Mark W., and Eberhardt Rechtin. 2009. *The Art of Systems Architecting.* Boca Raton, FL: Taylor & Francis Group, LLC.

Marine Corps Expeditionary Energy Office. 2014. “ExFob Team.” Accessed June 17. http://www.hqmc.marines.mil/e2o/ExFOB/ExFOBTeam.aspx.

———. 2011. “United States Marine Corps Expeditionary Energy Strategy and Implementation Plan: “Bases-to-Battlefield.”“ Washington, DC: Marine Corps Expeditionary Energy Office.

Marine Corps System Command. 2014. "Home of the Marine Corps Acquisition Professionals." Marines. Last accessed June 17. http://www.marcorsyscom.marines.mil/AboutUs.aspx.

Marine Corps Warfighting Laboratory. 2012. "Expeditionary Warrior 2012." Quantico, VA: United States Marine Corps.

McIntosh, Gregory C., David P. Galligan, Mark A. Anderson, and Michael K. Lauren. 2007. "MANA (Map Aware Non-Uniform Automata) Version 4 User Manual." Auckland, New Zealand: Operations Analysis Section, Defense Technology Agency.

Military.com. 2014. "M134 GAU-17 Gatling Gun." Military.com Last modified 2014. http://www.military.com/equipment/m134-gau-17-gatling-gun.

MilitaryFactory.com. "Beretta M9 - Semi-Automatic Service Pistol." Military Factory. Last modified October 16. http://www.militaryfactory.com/smallarms/detail.asp?smallarms_id=4.

Military-today.com. 2014. "CH-53K King Stallion." Last modified 2014. http://www.military-today.com/helicopters/ch53k_king_stallion.htm.

Mundfrom, Daniel J., Jay Schaffer, Myoung-Jim Kim, Dale Shaw, Ampai Thongteeraparp, and Pornsin Supawan. 2011. "Number of Replications Required in Monte Carlo Simulation Studies: A Synthesis of Four Studies." *Journal of Modern Applied Statistical Methods 2011* Vol. 10: Iss. 1, Article 4.

MzNobody. 2013. *Wikimedia Commons.* Last modified June 20. http://commons.wikimedia.org/wiki/File:AN_PRC_113.jpg.

NAVAIR. 2014. Aircraft. Last accessed October 17. http://www.navair.navy.mil/v22/?fuseaction=aircraft.main.

———. 2012. "H-1 Program AH-1Z and UH-1Y." Bell Helicopter. http://www.bellhelicopter.com/MungoBlobs/160/549/Bell_H1_OverviewBook.pdf.

Naval Postgraduate School. 2014. "Applying Model-Based Systems Engineering (MBSE) to Link Mission and Energy During Expeditionary Operations." *Background on O132 Capstone Projects.* Naval Postgraduate School.

Nelson, Doug. 2013. "Problem Definition and Stakeholder Analysis." Class Notes from SE3100 (Fundamentals of Systems Engineering). Last modified January 2.

Northrop Grumman Corporation. 2014. "AN/AAQ-24(V) DIRCM (Directional Infrared Countermeasure)." Northrop Grumman. Last modified 2014. http://www.northropgrumman.com/Capabilities/DIRCM/Pages/default.aspx?utm_source=PrintAd&utm_medium=Redirect&utm_campaign=LaserDIRCM_Redirect.

———. 2014. "AN/APR-39B(V)2 Radar Warning Receiver/Electronic Warfare Management System." Northrop Grumman. Last modified 2014. http://www.pavehawk.com/docs/APR-39BV2.pdf.

Olive-Drab. 2011. "AN/PRC-113." Olive-Drab. Last modified October 12. http://olive-drab.com/od_electronics_anprc113.php.

Pathirana, Chamal. 2012. *Wikimedia Commons.* Last modified May 19. http://commons.wikimedia.org/wiki/Category:Land_Rover_Defender_in_military_service#mediaviewer/File:Sri_Lanka_Military_0192.jpg.

Raymer, Daniel P. 2003. "An Approximate Method of Deriving Loiter Time From Range." Conceptual Research Corporation. Last modified February 07. http://www.aircraftdesign.com/raymerapproxloitertime.pdf.

Rivera, Cpl. Jackeline Perez. 2014. "CH-53E Super Stallion Transports Troops, Cargo." Defense Video & Imagery Distribution System. Last modified July 31. http://www.dvidshub.net/news/137878/ch-53e-super-stallion-transports-troops-cargo#.VEkLTfldWIw.

Rosenthal, Elisabeth. 2010. "Military Orders Less Dependence on Fossil Fuels." *The New York Times.* Last modified October 04. http://www.nytimes.com/2010/10/05/science/earth/05fossil.html?pagewanted=all&_r=0.

Sanandros. 2008. *Wikimedia Commons.* Last modified March 07. http://commons.wikimedia.org/wiki/File:AKS-74.jpg.

Sikorsky. 2014. "CH-53K Helicopter: The world's premier heavy lift helicopter is in development at Sikorsky." Sikorsky. Last modified 2014. http://www.sikorsky.com/Pages/Products/Military/CH53/CH53K.aspx.

Skahen, LT Stephen "Jack," USN, Steven Benner, Michael Boyett, Michael Brookhart, and Josue Kure. 2013. "Exploring the Reduction of Fuel Consumption for Ship-to-Shore Connectors of the Marine Expeditionary Brigade." Capstone Report, Naval Postgraduate School.

Sof, Eric. 2012. "Baikal MP-444 Baghiira Pistol." Special-ops.org. Last modified November 12. http://www.special-ops.org/baikal-mp-444-baghira-pistol/.

SupplyNet Tactical Engineering Division. 2014. “BA-5590 Battery Info.” SupplyNet. Last modified 2014. http://www.tacticaleng.com/c2/BA-5590-Battery-Info-c7.html.

Symetrics Industries. 2014. “AN/ALE-47 Countermeasures Dispenser System.” Symetrics Industries: Communication, Systems and Telemetry Products and Contract Manufacturing. Last modified 2014. http://www.symetrics.com/content/products/anale47/index.aspx.

Tarantola, Andrew. 2014. “The New King of High-Sea Helicopters Can Hoist 13 Tons.” Last modified May 12. http://gizmodo.com/the-new-king-of-high-sea-helicopters-can-hoist-13-tons-1574031173.

TRADOC DCSINT. 1999. “Worldwide Equipment Guide.” *fas.org*. Last modified January 21. http://fas.org/man/dod-101/sys/land/row/weg.pdf.

Training and Education Command United States Marine Corps. 2014. “Training and Education Command.” Last accessed June 17. http://www.tecom.marines.mil/.

United States Army Training and Doctrine Command. 2004. *Operational Terms and Graphics* (FM1-02). Fort Leavenworth: U.S. Army Training and Doctrine Command.

United States Marine Corps. 2002. *MCWP 3–11.2: Marine Rifle Squad*. Washington, DC: Department of the Navy Headquarters United States Marine Corps.

———. 2011. *Marine Corps Operations MCDP 1–0*. Washington, DC: Department of the Navy.

———. 2011. “MPEM Users Manual - MAGTF Power and Energy Model Version 1.8.2.” United States Marine Corps. Last modified July 15.

———. 2012. *U.S. Marine Corps S&T Strategic Plan - Leading Edge Technology for the Marines of Tomorrow*. Washington, DC: United States Marine Corps.

———. 2014. .”50 Cal Machine Gun Specifications.” Last modified 2014. http://www.marines.com/operating-forces/equipment/weapons/50-cal-machine-gun#specifications.

———. 2014. “60mm Mortar/81mm Mortar.” Last modified 2014. http://www.marines.com/operating-forces/equipment/weapons/60mm-mortar-81mm-mortar.

———. 2014. “CH-53E Super Stallion.” Last modified 2014. http://www.marines.com/operating-forces/equipment/aircraft/ch-53e-super-stallion.

———. 2014. *Expeditionary Force 21*. Washington, DC: Headquarters United States Marine Corps.

———. 2014. "HMMWV." Last modified 2014. http://www.marines.com/operating-forces/equipment/vehicles/hmmwv#features.

———. 2014. "M16." Last modified 2014. http://www.marines.com/operating-forces/equipment/weapons/m16.

———. 2014. "M240B." Last modified 2014. http://www.marines.com/operating-forces/equipment/weapons/m240b-machinegun.

———. 2014. "M249 SAW." Last modified 2014. http://www.marines.com/operating-forces/equipment/weapons/m249-squad-automatic-weapon-saw.

———. 2014. "M9 Beretta." Last modified 2014. http://www.marines.com/operating-forces/equipment/weapons/beretta-m9-pistol.

———. 2014. "Marine Corps Installations Pacific." Last accessed October 16. http://www.mcipac.marines.mil/Portals/28/Documents/MV22Factsheet.pdf.

———. 2014. "Marine Corps Task List (MCTL - 2.0)." Last modified January 2014. http://www.mccdc.marines.mil/Units/MarineCorpsTaskList.aspx.

———. 2014. "Marine Expeditionary Brigade CONOPS (Draft 1.18)." Last modified May 21. www.mccdc.marines.mil/ef21.

———. 2014. "MV-22 Osprey." Last modified 2014. http://www.marines.com/operating-forces/equipment/aircraft/mv-22-osprey.

US Federal Government. 1984. *Wikimedia Commons*. Last modified November 17. http://commons.wikimedia.org/wiki/File:PKM_DD-ST-85-01257.JPEG.

———. 2005. *Wikimedia Commons*. Last modified June 13. http://commons.wikimedia.org/wiki/M16#mediaviewer/File:M16A4_1.jpg.

———. 2006. *Wikimedia Commons*. Last modified January 22. http://commons.wikimedia.org/wiki/File:USMCAmbulance.jpg.

———. 2007. *Wikimedia Commons*. Last modified April 02. http://commons.wikimedia.org/wiki/File:FileArmy_IOTV.jpg.

———. 2008. *Wikimedia Commons*. Last modified June 07. http://commons.wikimedia.org/wiki/File:070907-jgsdf.jpg.

———. 2010. *Wikimedia Commons*. Last modified April 18. http://commons.wikimedia.org/wiki/File:M224_60mm_Mortar.jpg.

———. 2010. *Wikimedia Commons*. Last modified May 25. http://commons.wikimedia.org/wiki/File:PEO_M240B_Profile.jpg.

US Marines.mil. 2014. *Wikimedia Commons*. Last modified May 05. http://commons.wikimedia.org/wiki/File:CH-53K_Rollout.JPG.

Vectors4all.net. 2013. “Download Armed Hummer Clip Art Vector For Free!” Vectors4all.net. Last modified October 01. http://www.vectors4all.net/vectors/armed-hummer-clip-art.

What-When-How. 2014. “Mortars (Military Weapons).” What-When-How In Depth Tutorial and Information. Last Accessed October 22. http://what-when-how.com/military-weapons/mortars-military-weapons/.

Worldwide-Military.com. 2014. “Boeing AH-64 Apache.” World Wide Military. Last modified June 29. http://www.worldwide-military.com/Military%20Heli’s/Attack%20heli/Links/AH-64%20_Apache_EN.htm.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, VA

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, CA