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THESIS

EFFECTIVENESS OF NON-LETHAL CAPABILITIES IN A MARITIME ENVIRONMENT

by

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September 2006

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EFFECTIVENESS OF NON-LETHAL CAPABILITIES IN A MARITIME ENVIRONMENT

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ABSTRACT

The attack on the USS Cole within a civilian port, and the increased threat of pirating and terrorism on the high seas, underscore the immediate need for a maritime non-lethal capability. This research uses modeling and simulation to explore the requirements and tactical use of non-lethal capabilities in a maritime force protection mission. Specifically, a multi-agent simulation emulates a tactical-level mission in which a U.S. Navy vessel returning to Naval Station, Norfolk, VA, encounters a variety of maritime surface threats. Data farming is the method used to address the research questions by applying high performance computing to the simulation model, with the intent of examining a wide range of possibilities and outcomes. The non-lethal capabilities are analyzed in their effectiveness to 1) determine intent, 2) deter inbound surface vessels, and 3) engage targets identified as hostile through the continuum of force.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHD	Acoustic Hailing Device
ANOVA	Analysis of Variance
CBA	Capabilities-Based Assessment
CEP	Circular Error Probability
DOD	Department of Defense
DOE	Design of Experiment
EA	Executive Agent
EZ	Exclusion Zone
FAA	Functional Area Analysis
FNA	Functional Needs Analysis
FSA	Functional Solutions Analysis
JCIDS	Joint Capabilities Integration and Development System
JNLWD	Joint Non-Lethal Weapons Directorate
JNLWP	Joint Non-Lethal Weapons Program
JROC	Joint Requirements Oversight Council
KSL	Kolmogrov-Smirnov-Lilliefors
LRAD	Long Range Acoustic Device
MAS	Multi-Agent Simulation
MNS	Mission Needs Statement
MOE	Measure of Effectiveness
MOOTW	Military Operations Other Than War
MORS	Military Operations Research Society
NAVSTA	Naval Station
OD	Optical Dazzler
PIM	Plan of Intended Movement
ROE	Rules of Engagement
ROMO	Range of Military Operations
WM	Warning Munitions
XML	eXtensible Markup Language

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EXECUTIVE SUMMARY

The terrorist attack on the USS Cole on October 10, 2000, re-energized national efforts towards preserving freedom of the seas and safe access to ports, with a directed focus on force protection initiatives and technology. The tremendous potential of non-lethal capabilities in maritime force protection has been recognized by the Quadrennial Defense Review as well as an independent study conducted by the Naval Studies Board. This research, sponsored by the Joint Non-Lethal Weapons Directorate, directly impacts the current development of non-lethal requirements and tactics needed for effective maritime security.

To scope the analysis efforts, the following research questions of interest were identified for an entering port force protection mission:

- What non-lethal capabilities are required for a maritime force protection mission?
- When are non-lethal capabilities tactically appropriate?
- What are the geographical effects?
- How are non-lethal capabilities used to identify threats from non-threats?
- Is Multi-Agent Simulation (MAS) an appropriate modeling tool?

The first step in answering these questions was to develop a scenario within the MAS environment that appropriately emulated a Navy ship's ability to do three tasks: 1) Identify potential threats; 2) Determine intent of approaching small vessels; and 3) Deter vessels from closing within the 100 yard naval protective zone.

With the scenario developed, the next step was to apply an efficient design of experiment (DOE) using distributed simulation in order to capture a reasonable region of possible outcomes. The final scenario was simulated over a range of 33 input variables. These input factors included everything from requirements of the non-lethal capabilities such as range and firing rates, to quantified intangibles, such as fear and aggression levels of inbound targets.

Through the power of simulation, over three quarters of a million data points were generated. The key element in tying the data to the research questions was the Measures of Effectiveness (MOEs) selected for analysis. The following MOEs were defined specifically for this research:

- MOE 1 - Deterrence Ratio: The percentage of time the targets are deterred.

- MOE 2 – Hostile Identification Ratio: The percentage of time targets are identified as hostile, engaged, and subsequently killed, with lethal force.

- MOE 3 – Warning Zone Identification Ratio: If identified as hostile, the percentage of time the targets are identified, using non-lethal capabilities, outside the threat zone.

Using multiple data mining techniques, ordinary statistics, and visualization tools, the mammoth amount of data was efficiently analyzed to provide insight on the research questions. Key insights into non-lethal requirements and tactical application include:

- The employment of non-lethal capabilities is extremely effective when used to identify threats from non-threats in an ambiguous situation.

- Inbound speed is the critical factor in identifying and engaging inbound hostile threats outside of the exclusion zone.

- The number of inbound targets has little to no impact on identification and engagement rates of hostile targets.

- The first response non-lethal capability is the most crucial in deterring non-suicidal targets.

- The AHD is significantly more effective when employment time is less than 30 seconds against hostile targets and 1 minute for neutral or loitering targets.

- When used alone, counter-personnel non-lethal capabilities fail to deter loitering targets who attack when within close proximity.

With a limited number of non-lethal capabilities applied to a very specific mission, this thesis researched what other possible applications are appropriate using the methodology applied. Follow-on work was identified for three primary research areas:

Requirements – This research modeled three counter-personnel non-lethal capabilities. Future work should include scenario expansion to include counter-material capabilities.

Tactics – The scenario simulated involved one primary tactic adapted from current U.S. Navy tactics. Future work should include a comparative analysis of new tactics, especially in areas where this research deemed current tactics fall short.

Vulnerability Assessments – In addition to exploring the requirements and tactics of the non-lethal capabilities, this research was very effective in exploring the geographic vulnerabilities of the modeled port. Given this success, future work should apply this methodology to other geographic ports or chokepoints of interest in order to assist in anti-terrorism/force protection planning prior to ship arrival.

In summary, this research used cutting edge modeling and simulation to effectively emulate a complex scenario where little historical performance data exists. This thesis produced valuable insights through application of proven operations research tools and techniques, and provides a revolutionary compliment to subject matter expertise in non-lethal requirements and tactics development early in the acquisition process.

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I.   INTRODUCTION

Preserving the freedom of the seas is a top national priority. The right of vessels to travel freely in international waters, engage in innocent and transit passage, and have access to ports is an essential element of national security.*

The National Strategy for Maritime Security

A.   BACKGROUND OF NON-LETHAL CAPABILITIES

1.   Defining the Need for Non-Lethal Capabilities

Libya, Lebanon, Panama, Somalia, Bosnia, Haiti, and Kosovo: Over the past 20 years, these are the countries that have been the theater of operations for the U.S. military. Yet, despite the presence and action of the U.S. military, none of these operations were deemed wars. In fact, the last Congressional declaration of war was World War II (*Declaration of War by the United States,* 2006), yet U.S. military power has been projected many times since. After the Cold War, the U.S. shifted its policies when committing its forces. Specifically, U.S. decision makers expanded from the use of military force strictly for conventional war to the application of forces over a wide spectrum of military operations. This shift in the application of military force has had a significant impact on training, doctrine, and capabilities of U.S. forces.

This is most clearly exemplified in the differing national strategies between the two eras. NSC-68, which was the guiding principal for national strategic objectives in the Cold War, defines four possible courses of action: 1) Continuation of current policies; 2) Isolation; 3) War; and 4) A more rapid building up of the political, economic, and military strength (National Security Council, 1950). Of these, war is the only action which incorporates actual use of military forces.

In reaction to the first attack on the World Trade Center, the two attacks on U.S. embassies in Africa, the assault on the USS Cole, and finally, the mass terrorist attack on the Twin Towers and the Pentagon in September 2001, the administration adopted a new

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* Department of Defense and Homeland Security. (2005). *The National Strategy for Maritime Security.* Washington D.C.

approach towards the National Security Strategy that fundamentally differed from any seen before. Specifically, the Bush administration embraced preventive war. The most significant point of this National Security Strategy is the motivation to go beyond preemptive strikes and adopt a policy towards preventative action before threats even have the chance to develop.

Given the U.S. military's experience in non-wartime situations, military doctrine encompasses the concepts of the current National Security Strategy. The range of military operations (ROMO), as shown in Figure 1, describes military operations extending from war to military operations other than war (MOOTW).

RANGE OF MILITARY OPERATIONS

Military Operations	General US Goals	Representative Examples
COMBAT — War	Fight & Win	Large Scale Combat Operations Attack / Defend / Blockade
NONCOMBAT — Military Operations Other Than War	Deter War & Resolve Conflict	Peace Enforcement Counterterrorism Show of Force/Raid/Strike Peacekeeping/NEO Nation Assistance Counterinsurgency
NONCOMBAT — Military Operations Other Than War	Promote Peace & Support US Civil Authorities	Freedom of Navigation Counterdrug Humanitarian Assistance Protection of Shipping US Civil Support

Figure 1.   Range of Military Operations (From Chairman Joint Chief of Staff, 1995)

The idea of preventative action is captured within the purpose of MOOTW, which is to deter war and promote peace. Because MOOTW are preventative in nature and generally involve non-combatant civilians, they follow more restrictive rules of engagement (ROE) (Chairman Joint Chief of Staff, 1995). As such, non-lethal capabilities have been identified as a significant tool in accomplishing MOOTW missions, as well as enhancing mission effectiveness in conventional combat operations.

2.   History of Non-Lethal Capabilities Development

Although numerous examples of non-lethal employment can be extrapolated from history, the first formal instance of non-lethal capabilities directly utilized to support a U.S. military objective is the U.S. intervention in Somalia. LtGen Anthony Zinni, tasked with the withdrawal of UN troops from Mogadishu, called for the immediate fielding of non-lethal capabilities in order to minimize casualties and mitigate escalation (*Non-lethal Weapons,* 2005).

By 1996, the Department of Defense released Directive 3000.3, officially establishing the Joint Non-Lethal Weapons Program (JNLWP), Non-Lethal policies, and DOD-wide responsibilities for non-lethal development. From this, the Commandant of the Marine Corps, serving as the executive agent (EA) for JNLWP, established the Joint Non-Lethal Weapons Directorate (JNLWD). The JNLWD serves as the central liaison for all issues involving non-lethal capabilities, including research and development, science and technology, requirements, and acquisition of non-lethal technologies (*The Joint Non-Lethal Weapons Program,* 2005).

In December 2002, the Defense Department's Joint Requirements Oversight Council (JROC) approved a Mission Need Statement (MNS) expressing the need for non-lethal capabilities in order to "break the cycle of violence that often prolongs or escalates conflict" (Allison et al., 2004). In 2004, the Council on Foreign Relations released a report recommending more intensive use of current non-lethal capabilities as well as aggressive development of new non-lethal concepts (Allison et al., 2004). In response, the JNLWP EA issued a directive requiring a Capabilities-Based Assessment (CBA) for all non-lethal weapons and capabilities. In accordance with the Chairman of the Joint Chiefs of Staff Instruction 3170.01 for the Joint Capabilities Integration and Development System (JCIDS), the JNLWD spearheaded a JCIDS analysis. The objectives of this analysis were to meet the EA's directive and update the previous JROC MNS (*Functional Area Analysis,* 2004). Figure 2 depicts the objective of the JCIDS analysis at each step.

JCIDS ANALYSIS
(DoD Prescribed Four-Step Process)

- **Functional Area Analysis**
  - Develop Operational Tasks, Conditions, and Standards
- **Functional Needs Analysis**
  - Determine Gaps and Timeframe
- **Functional Solutions Analysis**
  - DOTMLPF Analysis
  - Ideas for Materiel Approaches
  - Analysis of Materiel Approaches
- **Post Independent Analysis**
  - Sponsor Prioritizes Solutions and Actions

Figure 2.   The Four Steps in the JCIDS Process (From *Functional Area Analysis*, 2004)

3.   Non-Lethal Capabilities and the Maritime Environment

The attack on the USS Cole within a civilian port, and the increased threat of pirating and terrorism on the high seas, underscored the immediate need for a maritime non-lethal capability. This research seeks to focus on non-lethal capabilities in the maritime environment, and therefore will only address elements of the JCIDS analysis which focus on the key maritime terrain. The JCIDS' Functional Area Analysis (FAA) determined which maritime tasks can be supported by non-lethal capabilities. The conclusion was the identification of 18 tasks that apply to the maritime terrain. The FAA validated the relevance of non-lethal capabilities in accomplishing critical missions at sea. The second JCIDS step was to conduct the Functional Needs Analysis (FNA), one of the two major findings identified that current and projected non-lethal capabilities fail to satisfy conditions involving maritime tasks. Further conclusions showed that performance gaps existed in most standards required of non-lethal capabilities to include range, coverage, duration, effects and reversibility (*Functional Needs Analysis,* 2004). Based on the gaps identified in the FNA, the Functional Solutions Analysis (FSA) focused on material and non-material solutions needed for mitigation. The primary finding of the FSA was, "Gaps identified during the FNA are mainly caused by the physical limitations of current non-lethal capabilities" (*Functional Solutions Analysis,* 2005).

In a separate assessment, the Naval Studies Board defined the need for non-lethal capabilities in a variety of U.S. Navy missions. The assessment divided the missions into defensive and offensive objectives. The primary defensive mission identified was force protection while the offensive missions included maritime interdiction, blockades and strikes (Naval Studies Board, 2003). In its conclusions, the assessment noted four areas of concern. The following two contribute to the underlying motivation for this research:

- Without a much stronger overall program to understand and characterize the effects and effectiveness of non-lethal weapons, commanders will remain reluctant to request or employ them (Naval Studies Board, 2003).

- Without concepts for the use of non-lethal weapons, developers will not be successful in focusing ideas and programs (Naval Studies Board, 2003).

B. OBJECTIVE

The JCIDS FSA conclusion that new non-lethal capabilities are needed and the Naval Studies Board assessment that understanding effectiveness and developed concepts are critical for non-lethal implementation drive the main questions investigated in this work. This research seeks to use modeling and simulation to explore the requirements, effectiveness and tactical use of non-lethal capabilities for a maritime force protection mission.

C. SCOPE OF THESIS AND RESEARCH QUESTIONS

This research will focus on a tactical-level scenario in which a U.S. Navy vessel returning to Naval Station (NAVSTA), Norfolk, VA, will encounter a variety of maritime surface threats. The objective of the U.S. Navy vessel is to reach the terminal point (NAVSTA pier). En route to the objective point, the U.S. Navy vessel will employ non-lethal capabilities as appropriate.

The primary research question of this thesis is:

- What non-lethal capabilities are required in a maritime force protection environment in order to effectively determine intent and/or deter suspicious small vessels?

Supporting questions are as follows:

- Is a multi-agent simulation (MAS) an appropriate means to represent and analyze a ship's ability to determine intent and use continuum of force?

- In what region of conditions are non-lethal capabilities tactically appropriate against high speed hostile threats?

- What, if any, are the major differences in requirements given varying geographic constraints?
- What requirements are needed of non-lethal capabilities in order to effectively separate threats from non-threats in a homogeneous group?

D.   METHODOLOGY

The systematic approach of this research is to apply a process called data farming, an analytic process initially designed to support research and development efforts of the Marine Corps Warfighting Laboratory's Project Albert. Data farming is a method used to address decision makers' questions by applying high performance computing to a simulation model, with the intent of examining a wide range of possibilities and outcomes (*Project Albert,* 2006). By incorporating cutting edge experimental designs developed at the Naval Postgraduate School into the data farming process, thousands of data points are collected and analyzed in order to identify significant factors, interactions between key variables, and critical performance thresholds (Cioppa, 2002; Kleijnen et al., 2005; Cioppa and Lucas, 2006).

The following chapters provide the specific background on each facet of the data farming process as applied to non-lethal capabilities in the maritime environment. Chapter II describes the tactical scenario designed for this research.   The chapter discusses the assumptions and methodology used to emulate tactically-significant interactions between maritime vessels using a multi-agent simulation (MAS). Chapter III addresses how a robust set of data is created by implementing an efficient design of experiment (DOE) and leveraging high power computing power. Details include which initial conditions and parameters will be varied in order to explore the wide spectrum of possible real-world outcomes. Chapter IV focuses on the analysis of the data after the DOE is applied. Specifically, this chapter discusses the motivation behind the measures of effectiveness (MOE) selected, how these MOEs are extracted from the simulation process, and what statistical insight is garnered in answering the primary research and future applications of this research.

II.   SCENARIO DESCRIPTION

It is impossible to foresee, or to fully comprehend, all the challenges we will face. But by building a balanced force that is resilient and adaptable, with the depth of capabilities required to meet the demands of a multi-mission, multi-task environment, we can mitigate against this uncertainty.[†]

Admiral Mike Mullen

A.   OVERVIEW

The primary objective of this research is to use modeling and simulation to capture the required non-lethal capabilities to deter terrorist attack or determine hostile intent of maritime assets. A realistic scenario within the modeling and simulation environment provides the foundation for this analysis. This chapter describes the model selection and scenario design implemented for this specific research.

B.   MODEL SELECTION

1.   Multiple Agent Simulations

Determination of intent and deterrence of a target are both *decisions* made by one side or the other. In the real world, many factors such as weather, terrain, and the physical capabilities and limitations of the players drive the decision making process. These features can be captured in a physics-based or probability-based model. However, human factors, such as morale, confidence, fatigue, and intelligence, are also critical elements of the hostile decision to continue the attack or be deterred. They are also key factors in the shipboard decision to recognize the threat and take non-lethal or lethal action. The previously mentioned models generally ignore these factors. For this reason, this research uses multi-agent simulation (MAS) in order to capture the *intangibles*, such as fear and aggression, which are essential to effectively emulate the decision making processes.

Although definitions vary, the primary distinction of MAS is that it is made up of agents, or entities, that behave autonomously and are capable of *choice* given a simple set of rules or logic (Sanchez and Lucas, 2002). Like probability-based models, MAS incorporate probabilities in order to account for random effects. One goal for this

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[†] Mike G. Mullen, (2006). *CNO Guidance for 2006: Meeting the Challenge for a New Era.* Retrieved July 8, 2006 from http://www.globalsecurity.org/military/library/policy/navy/cno-guidance_2006.html.

scenario is to simulate the choice of a surface target to deter. This choice is based on how influenced the target is by, or how 'afraid' it is of, the U.S. Navy ship. A target's decision whether or not to deter is also a factor of how aggressive that target is. For example, a target that is hostile in nature will show more aggressiveness and less fear than a neutral target, and consequently will be less likely to deter. These levels of fear and aggression which drive agents' choices and resultant actions are captured using MAS.

2.   Why PYTHAGORAS?

The MAS chosen for this research is PYTHAGORAS, a Northrop Grumman product. Three reasons influence the selection of this model. First, PYTHAGORAS offers a unique set of capabilities appropriate for this research (Bitinas et al., 2006). Specifically, PYTHAGORAS

- Incorporates *soft rules* to distinguish unique agents;
- Uses *desires* to motivate agents into moving and shooting;
- Includes the concept of *affiliation* (established by *sidedness*, or color value) to differentiate agents into members of a unit, friendly agents, neutrals, or enemies;
- Allows for behavior-changing events and actions (called *triggers*) that may be invoked in response to simulation activities; and
- Retains traditional weapons, sensors, and terrain.

Second, PYTHAGORAS is specifically designed to be compatible with data farming, the primary method used for data collection and analysis in this research (see Chapter IV).

Third, as a U.S. developed model, this research can be applied to quickly assist our operating forces in exploiting vulnerabilities and determining tactics to mitigate risk within ports and choke points throughout the world.

C.   MODEL CONFIGURATION

1.   Scale

The first step in building a scenario in PYTHAGORAS is defining what a time step and pixel distance mean. All subsequent terrain features, weapons and sensor ranges, firing rates, and speeds depend on the pixel distance and/or the amount of time encompassed by a time step (Bitinas et al., 2006).

The original intent was to create a scenario representing the entrance to Thimble Shoals Channel, Norfolk, VA, to the Elizabeth River, Norfolk, VA. This area covers a 25 nautical mile by 15 nautical mile area. When translated to the 1000 pixel by 1000 pixel PYTHAGORAS terrain box, each pixel represented nearly 50 yards. In a real-world scenario involving a high speed small boat, much can occur over 50 yards. In order to capture more range fidelity, the real-world area of interest was refined.

The scenario was re-scaled to a 9.5 nautical mile by 9.5 nautical mile area, focusing on the entrance to the Elizabeth River from Thimble Shoals Channel. Translating onto the 1000 pixel by 1000 pixel terrain box, each pixel represents approximately 19 yards. This offers almost three times as much range fidelity. With a time step defined as 0.25 minutes, the blue ship takes approximately 85 minutes (300 time steps) to reach its objective point. Table 1 lists how various units of distance, time and speed are represented by the defined pixel and time step measurements.

	Pixel	*1*	*10*	*100*
	Miles	0.01	0.11	1.10
	Yards	19.36	193.60	1936.00
Distance	Kilometers	0.02	0.18	1.77
	Meters	17.70	177.03	1770.28
	Nautical Miles	0.01	0.10	0.96
	Time Step	*1*	*4*	*400*
Time	Minutes	0.25	1.00	100.00
	Hours	0.00	0.02	1.67
	Pixels/Time Step	*1*	*5*	*11*
Speed	miles/hour	2.64	13.20	29.04
	kilometers/hour	4.25	21.24	46.74
	knots	2.29	11.47	25.24

Table 1.   Pixel and Time Step Translations

2.   Terrain

PYTHAGORAS terrain features offer many options to include height, protection, concealment, and trafficability. For this scenario, grey terrain represents land. No agents can move through land and neither detections nor engagements can occur through land. Yellow terrain represents land features which an agent cannot pass through, but do not offer 100% concealment as grey terrain does. Blue terrain represents water. It is assumed that the blue ship will remain on its track within the channel and all small boat

threats have sufficiently small drafts to traverse across water of any depth. Therefore, the blue terrain is 100% trafficable and all targets are detectable when within sensor range. Figure 3 compares the actual area of interest versus the terrain constructed in the PYTHAGORAS model.
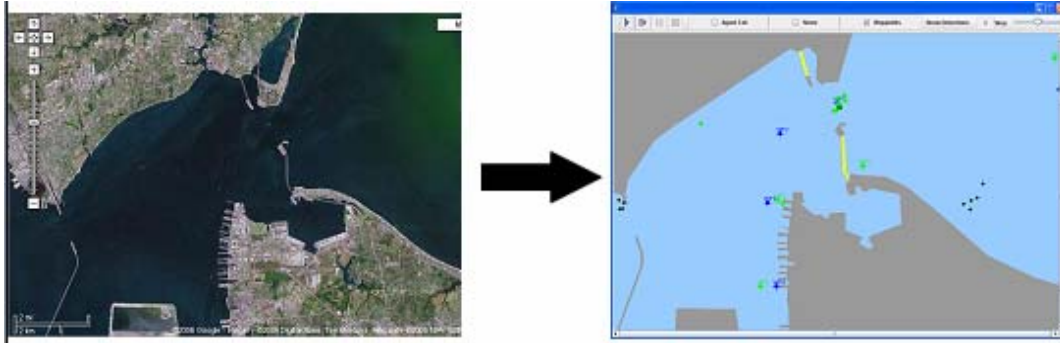
Figure 3.   Comparison of Actual Terrain (From Graphic Retrieved from Google Maps, 2006) and PYTHAGORAS Model Terrain

D.   BLUE AGENTS

In PYTHAGORAS, an agent class refers to a group of agents that share the same desires and capabilities. Although PYTHAGORAS allows for complex maneuvering, all blue (U.S.) agents are modeled to move together, consistent with current naval policies and procedures, at a constant speed along a point-to-point Plan of Intended Movement (PIM). The purpose for this maneuvering scheme is twofold. First, although observing a target's reaction to own-ship maneuvers is an effective means in determining intent, it is not always possible. In an entering port scenario, it is realistic that the entering ship is in a restricted channel operating under speed restrictions. In this situation, a U.S. Navy vessel must rely on non-lethal capabilities and communications to determine intent. The second reason is to prevent so much complexity in the model that the effects of the non-lethal capabilities cannot be analyzed effectively. Figure 4 highlights the PIM of the blue ship throughout the scenario.
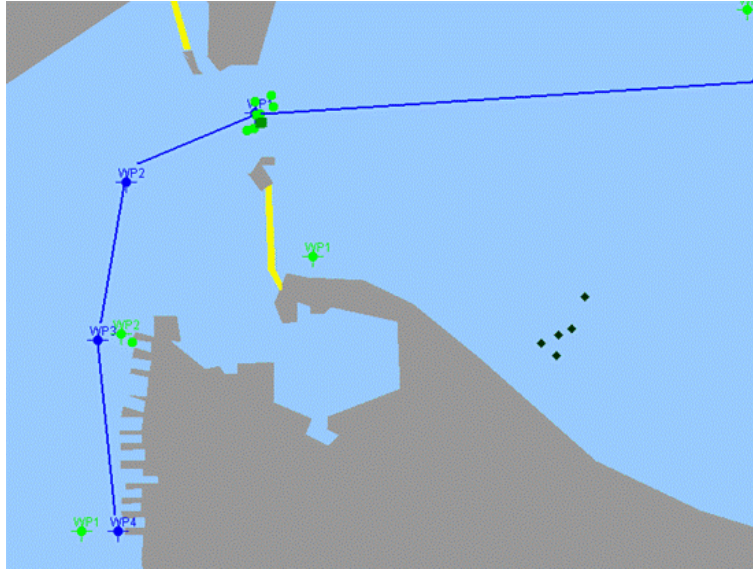
Figure 4.   Blue Ship PIM

For this scenario, all blue agents represent a single U.S. Navy ship. Each blue agent represents a capability, either non-lethal or lethal. The motivation for creating separate agent classes for each capability is to capture the rules of engagement (ROE) in the scenario. In other words, by defining different agent classes, the blue ship can assign the appropriate capability to different types of targets. For example, a target that is recently detected and has not been queried is eligible to be engaged by the Acoustic Hailing Device, but not by a lethal weapon. The five blue agent classes are: 1) Acoustic Hailing Device (AHD), 2) Optical Dazzler (OD), 3) Warning Munitions (WM), 4) Lethal, and 5) Lethal Exclusion Zone (EZ).

1.   Non-Lethal Capabilities

a.   Acoustic Hailing Device

AHDs use directed acoustic energy to provide a non-lethal warning capability by producing highly directional sound beams. These sound beams can be formed into either warning tones or voice commands (*AHD Fact Sheet*, 2006). In November, 2005, the cruise ship "Seaborne Spirit" used an AHD while successfully repelling armed pirates off the coast of Somalia (*Long Range Acoustic Device,* 2006). This operational use in the maritime environment inspires further research on the effectiveness of this capability in the key terrain of sea. It is modeled in this scenario as a direct capability with varying firing rates (depending on if its use is for a warning tone or

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voice commands). Figure 5 shows the Long Range Acoustic Device (LRAD), an AHD developed by American Technology Corporation, in use onboard a U.S. Navy patrol craft.

Figure 5.   The LRAD onboard USS Typhoon (From *Long Range Acoustic Device,* 2006)

b.   *Optical Dazzler*

An OD is a directed-energy capability that employs intense visible light, usually generated by a laser (*Dazzler,* 2006). The purpose of an optical dazzler is to provide visual warning and, as a target closes, optical disorientation. Where the AHD provides the blue ship with an audio capability, the OD is included to provide the blue ship with a visual capability. Since a dazzler are typically steady or strobe light, it is modeled in this scenario as a direct capability with a high rate of fire.

c.   *Warning Munitions*

WM's are projectile cartridges that create a bright flash, loud bang, and smoke when fired down range (*JNLWM Fact Sheet*, 2006). Although audio and visual capabilities are already assigned to the blue ship, the WMs model a more aggressive warning posture. They are modeled in this scenario as an indirect capability where a circular error probability (CEP) radius originates from the aim point. All targets within the CEP radius are affected by the WMs accordingly.

2.   Lethal Capabilities

a.   *Lethal*

Because this research focuses on the determination of intent and the escalation of force up to lethal means, the scenario does not attempt to model the lethality of a specific weapon type. Once a threat has been identified as a hostile threat, it is engaged with a 'one shot, one kill' lethal weapon. Although realistically a U.S. Navy

ship does not shoot and kill every target identified as hostile, this feature of the model is used later for data analysis. See Chapter 4 for a more detailed discussion.

b. *Lethal Exclusion Zone*

Navy tactics dictate that a target can be assumed to be hostile if it ignores all warnings and continues to close within a certain distance. To capture this within the model, a second lethal weapon is defined. The lethal (EZ) weapon is fired when any contact closes within 100 yards of the blue ship. This distance derives from the U.S. Coast Guard regulation on naval vessel protective zones stating that no vessel is allowed within 100 yards of a U.S. naval vessel without authorization (*Naval Protective Zones*, 2006). The purpose in having two lethal weapons defined is to extract which contacts are deemed hostile due to proximity versus those identified as hostile independent of range.

E. MODELING NON-LETHAL CAPABILITIES

1. Non-Lethal Capabilities Employment Tactics

The tactics used by the blue ship to engage contacts with non-lethal capabilities reflect the current U.S. Navy force protection architecture. Specifically, three zones are created around the blue ship for a layered defense (Naval Studies Board, 2003). In the first zone, the assessment zone, the blue ship must detect and assess if a target is a potential threat. At scenario start, the blue ship identifies all targets as neutral. The AHD is used to make an initial query and warn targets. In the second zone, the warning zone, the blue ship uses some or all of its non-lethal capabilities to deter continuing threats. If a target reaches the third zone, the threat zone, the intent of the approaching craft is assumed to be hostile (Naval Studies Board, 2003) and it is engaged with the lethal (EZ) weapon. Figure 6 illustrates the force protection architecture for this scenario.

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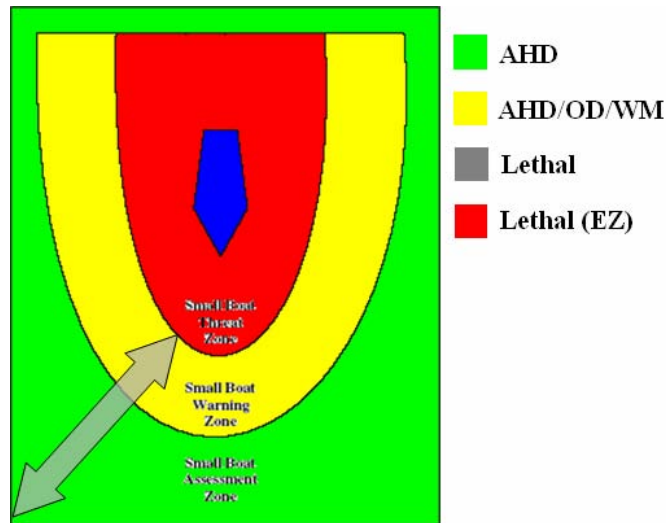
Figure 6. Layered Defense against Small Boats (After Chief of Naval Operations, 2003)

To quote the Department of Defense (DOD) Directive 3000.3 "Policy for Non-Lethal Weapons," released on July 9, 1996, and recertified on November 21, 2003:

> Neither the presence nor the potential effect of non-lethal weapons shall constitute an obligation for their employment or a higher standard for employment of force than provided for by applicable law. In all cases, the United States retains the option for immediate use of lethal weapons, when appropriate, consistent with international law (Department of Defense, 2003).

The scenario captures this directive with the use of the lethal weapon. Regardless of range or what non-lethal capabilities have or have not been used, the blue ship will engage with lethal force in the first or second zone once the determination of hostile intent has been made. Appendix A demonstrates in detail how the PYTHAGORAS sidedness properties are used to model the continuum of force.

2. Non-Lethal Capabilities Effects

When talking about effects, this scenario does not try to capture the physical reaction of the non-lethal capabilities on a person or piece of equipment. The effects in this scenario refer to the targeting and maneuvering decisions of the agents in reaction to the employment of non-lethal capabilities. The following paragraphs describe the overall concept of these effects and how they control the blue ship's determination of hostile intent and a target's decision to deter.

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a.   *Suspicion Level*

The suspicion level represents how threatening a target is to the blue ship. Each time a non-lethal capability is employed against a target, and that target does not react or deter, the suspicion level against that target is raised.

b.   *Suspicion Level Threshold*

The suspicion level threshold is the amount of suspicion needed against a target for the blue ship to take further action. The most significant threshold is when enough suspicion has been built to declare hostile intent and escalate to lethal force. Sub-levels represent the continuum of force where the blue ship is triggered to use more aggressive capabilities.

c.   *Deterrence Level*

The deterrence level represents how influenced a target is when engaged by non-lethal capabilities. This level is cumulatively collected for every type and instance of non-lethal capability employment against a target.

d.   *Deterrence Level Threshold*

The deterrence level threshold is the amount of cumulative influence needed for a target to deter. For all threat types, once deterred, a target will maneuver away from the blue ship, regardless of initial movement desires.

3.   Hierarchy of Threats

In the real world, a U.S. Navy ship is not equally suspicious of all inbound targets. Watchstanders use the kinematics of a particular threat in determining its suspicion level. Two important kinematics used to determine intent are the number of targets grouped together and the speed of those targets. To capture this within the scenario, the blue ship groups inbound threats into one of four categories. Category I threats incite higher levels of suspicion than Category IV threats when blue ship warning and deterrence efforts are unheeded. Figure 7 defines the criteria for each threat category based on target numbers and speeds.

- Category I: 3 or more targets AND faster than 18 knots
- Category II: 3 or more targets OR faster than 18 knots
- Category III: 2 or less targets AND slower than 18 knots
- Category IV: Fishing or loitering targets

Suspicion Level
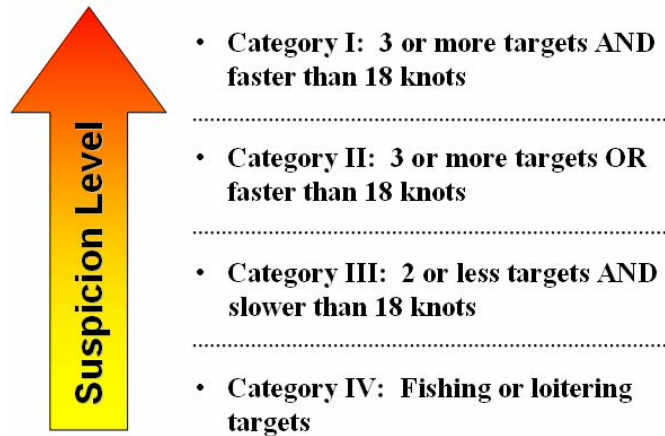
Figure 7.   Hierarchy of Threats

F.   THREAT AGENTS

The purpose of the threat agents in this scenario is to provide the blue ship with a realistic selection of threats that a U.S. Navy vessel could face when entering a port. It is important to understand that the naming convention used for these threats (hostile, neutral, and suspect) refers to the target's true identity (ground truth) and is completely independent of the blue ship's classification of the target.

1.   Hostile Targets

Hostile targets are designed to maneuver on a direct attack run towards the blue ship. In other words, they act as "suicide boats." As such, they have a higher deterrence threshold, meaning that they are less likely to be deterred by non-lethal capabilities. However, once the deterrence threshold is reached, hostile targets will break off the attack run for a variable amount of time, and then recommence the attack run. When a hostile target re-commits to an attack run, the blue ship retains all prior suspicion levels built up against that target. Conversely, the hostile target's deterrence level is re-initialized below the deterrence level threshold.

There are two groups of hostile targets in the scenario which represent two different attack tactics. The first group conducts an open water approach, giving the blue force early target detection and a longer prosecution time. The second group conducts a more covert maneuvering scheme. Here the enemy hides behind a jetty, denying early

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detection. When the blue ship nears its closest point of approach, the second group abandons its hiding position and commences its attack run. Figure 8 illustrates both hostile maneuvering tactics.
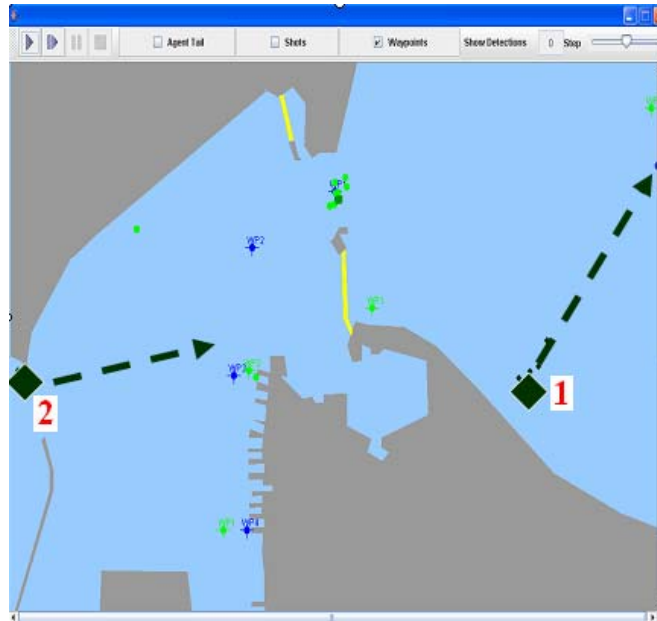
Figure 8.   Hostile Targets' Movement

2.   Neutral Targets

Neutral targets, like the blue ship, have their own PIM. However, since the neutral targets are closing in on the blue ship when detected and will pass within close proximity, the blue ship must decide if the approaching ship has ill intent or is simply a passerby. Neutral boats have a lower deterrence threshold and are more likely to be deterred by non-lethal capabilities. After the deterrence threshold is reached, a neutral target will still proceed to its next waypoint, but will maneuver as necessary to avoid the blue ship.

There are two types of neutral targets in the scenario which represent two different geographic situations when the blue ship reacts to the closing target. The first type represents a channel approach. Although the blue ship has early target detection, this situation forces the blue ship to deal with multiple types of threats at once when transiting through the chokepoint. The second type of neutral target represents a crossing ferry. Although neutral targets are more easily deterred, this situation poses a geographic

constraint where the neutral target may not have room to clearly maneuver away from the blue ship even though its deterrence threshold is met. Figure 9 illustrates both neutral maneuvering schemes.
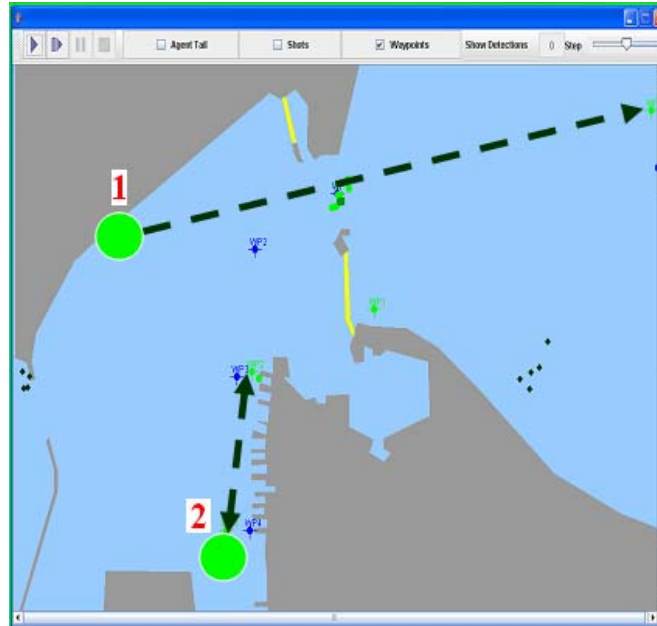
Figure 9.   Neutral Targets' Movement

3.   Neutral Fishing/Loitering Targets

These targets, like those described in the previous section, have a lower deterrence threshold. Yet instead of following a PIM, the neutral fishers loiter around a chokepoint through which the blue ship must transit. Additionally, they respond as a group in that once one of the targets reaches its deterrence threshold, the entire group will move to avoid the blue ship.

4.   Suspect Fishing/Loitering Targets

The suspect fishers represent a class of targets that are not as aggressive or overt as the hostile targets, but still desire to attack the blue ship. At scenario start, they loiter with the neutral fishers at a chokepoint and await a "target of opportunity." This creates the appearance of a homogenous group that is actually composed of different classes of threats. Once the blue ship moves within a close range, a suspect fisher will change its scheme of maneuver and commence a direct attack run on the blue ship. Unlike the hostile targets, once a suspect fisher reaches its deterrence threshold, it will move as

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necessary to avoid the blue ship (and once it is deterred, it will remain deterred). Figure 10 below highlights the chokepoint area where both neutral and suspect fishers are positioned.
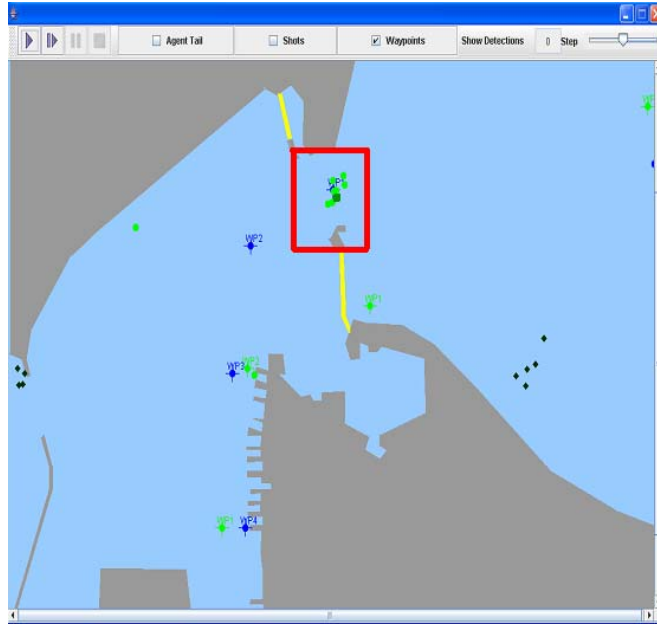
Figure 10.   Chokepoint with Loitering Targets

G.   SUMMARY

Although this scenario represents a range of threats, a single run represents only one possible outcome. Since little or no data exists on the reaction of surface maritime threats to newly developed non-lethal capabilities and accurately predicting the human factor inputs is problematic, a single run is not sufficient for this research. The next chapter discusses how an efficient design of experiment (DOE) and high power computing capabilities are used to analyze the trends in output given a wide variety of *possible* reactions from a target.

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III.   ANALYSIS METHODOLOGY

> Any intelligent fool can make things bigger, more complex, and more violent. It takes a touch of genius, and a lot of courage, to move in the opposite direction.[‡]
>
> Albert Einstein

A.   OVERVIEW

This thesis does not explore the physiological effects of non-lethal capabilities on personnel.   The 'effectiveness' in this scenario relates to the impact non-lethal capabilities have on the tactical objectives to 1) determine intent, 2) deter inbound surface vessels, and 3) engage targets identified as hostile with lethal force.

Figure 11 represents modeling and simulation as a function where the output of the simulation measures the effects of the inputs. Within the simulation environment, a set of input parameters are applied to the model and the output is recorded. The input parameters are then varied, and the model is run again. This iterative process is repeated until every input set of interest is applied to the model. The resultant Y vector is composed of literally thousands of values, representing the associated output for each set of input parameters. The methodology of this thesis is to build the right-side of the equation so that the resultant output is pertinent in answering the initial research questions.

$$\vec{Y} = \overset{\text{Model}}{\vec{F}(\vec{X})} + \vec{\varepsilon} \leftarrow \text{Error}$$

Output   Input & Model Parameters

Figure 11.   A Model/Simulation as a Big Function (From OA4655, 2005)

B.   MEASURES OF EFFECTIVENESS

To accomplish this, the first step is to determine what output is needed for useful analysis. One type of output is a measure of effectiveness (MOE). A MOE defined is a quantitative measure, generated by the model, used to compare the effectiveness of

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[‡]Albert Einstein*: Albert Einstein Quotes.* Retrieved July 21, 2006 from http://www.quotationspage.com/quote/24921.html.

alternatives in achieving the tactical objectives (OA4655, 2005). The following lists the MOEs designated for this research and to be applied in follow-on analysis.

- MOE 1 - Deterrence Ratio: The percentage of time the targets are deterred.

- MOE 2 – Hostile Identification Ratio: The percentage of time targets are identified as hostile, engaged, and subsequently killed, with lethal force. This MOE not only captures accurate identification of hostile threats, but misidentification of neutral targets.

- MOE 3 – Warning Zone Identification Ratio: If identified as hostile, the percentage of time the targets are identified, using non-lethal capabilities, outside the threat zone.

C.   VARIABLES OF INTEREST

With the PYTHAGORAS model selected and the scenario constructed, the next step is to define which input variables, or factors, are of interest. Table 2 outlines the factors chosen for the experimental design. Each factor is varied over a range in order to evaluate the underlying effects on the output. Each factor type is described in detail below.

Factor #	Factor ID	Factor Name	Min Pythagoras Value	Max Pythagoras Value
1	AHDMaxRange	AHD Maximum Range	25 (484 yds)	80 (1580 yds)
2	ODMaxRange	OD Maximum Range	15 (290 yds)	55 (1065 yds)
3	WMMaxRange	WM Maximum Range	5 (96 yds)	25 (484 yds)
4	AHDFirRate	AHD Firing Rate	0.17 (1.5 min)	0.5 (0.5 min)
5	ODRedRadRat	OD Red Radius Ratio	0.1	0.9
6	WMRedRadRat	WM Red Radius Ratio	0.1	0.9
7	LethalRedRad	Lethal Red Radius	15	50
8	>=3 & >=18	Color Vulnerability (Category I)	0.9	1
9	>=3 | >=18	Color Vulnerability (Category II)	0.7	0.9
10	<3 & <18	Color Vulnerability (Category III)	0.5	0.7
11-12	TNFColVul; TSFColVul	Target Fisher Color Vulnerability (Category IV)	0.1	0.5
13-14	THAttVul; TH2AttVul	Target Hostile Attribute Vulnerability	0.1	0.6
14-16	TNAttVul; TN2AttVul; TNFAttVul	Target Neutral Attribute Vulnerability	0.7	1
17-18	TSFAttVul	Target Suspect Attribute Vulnerability	0.4	0.8
19-20	THInst; TH2Inst	Target Hostile Instance	1	5
21	TNFInst	Target Neutral Fisher Instance	3	7
22	TSFInst	Target Suspect Fisher Instance	1	4
23-26	THSpd; TH2Spd; TNSpd; TN2Spd	Target 'Class' Speed	4 (9.2 kts)	11 (25.2 kts)
27	THAlphaLess	Target Hostile Alpha Less Than Value	200	240
28	TNAlphaLess	Target Neutral Alpha Less Than Value	230	250
29	TSFAlphaLess	Target Suspect Fisher Alpha Less Than Value	215	245

Table 2.   Farmable Factors

1.   Blue Factors

a.   AHD Maximum Range

This is the maximum range of the AHD. Although different AHDs exist and their capabilities are known, looking at variable maximum ranges in this scenario serves two purposes. First, currently fielded AHDs are mainly intended for land use. Varying the range of the AHD in this scenario explores the requirements needed over water. Second, this factor captures the performance of the AHD in varying conditions. For example, if the weather is very windy, thereby reducing the maximum effective range of the AHD, the data are still relevant for analysis.

b.   OD Maximum Range

This is the maximum range of the OD. Like the AHD, this variable explores requirements and effectiveness given varying conditions. In this case, different states of visibility affect the maximum range of the OD.

c. WM Maximum Range

This is the maximum range of the WM. As before, this variable explores requirements and effectiveness given varying conditions.

d. AHD Firing Rate

This defines the suppression duration of the AHD. Since its potential use ranges from immediate audio warnings to deliverable voice messages, this variable represents the time needed to employ the AHD against a target. For example, a longer firing rate represents the total time needed to broadcast a verbal message.

e. Color Vulnerability

The blue ship discriminates against inbound targets based on target kinematics, as discussed in Chapter 2 (Section E.3). This factor defines the suspicion level assigned to each category in the hierarchy of threats. Category I threats (target groups with three or more vessels traveling faster than 18 knots) create the highest level of suspicion, and in PYTHAGORAS terms, are assigned the highest color vulnerability.

f. OD Red Radius Ratio

This defines the suspicion level needed against a target before it is eligible to be engaged by the OD. This level will always be a proportion of the WM red radius.

g. WM Red Radius Ratio

This defines the suspicion level needed against a target before it is eligible to be engaged by the WM. This level will always be a proportion of the Lethal red radius.

h. Lethal Red Radius

This represents the suspicion level threshold. Once this level is reached, a target is identified as hostile and is immediately engaged by lethal force.

2. Target Factors

a. Target Instance

This is the number of targets grouped together for a particular threat type and location. This factor applies to the two hostile threat types and both neutral and suspect loitering types. For the neutral targets which represent an outbound vessel in the channel and a ferry crossing the channel, these threat categories are fixed at only one agent through all iterations.

b.   *Target Speed*

This is the average speed of the targets within a threat class. This factor applies to all non-loitering threats.

c.   *Target Attribute Vulnerability*

This factor affects the deterrence level of a target. Since neutral targets are more likely to be influenced by non-lethal capabilities, they assume a higher vulnerability than suspect and hostile targets. The deterrence level becomes a function of the target's attribute vulnerability and how often non-lethal capabilities are employed against them.

d.   *Target Alpha Less Than Value*

This factor captures the deterrence level threshold within the PYTHAGORAS model. Once a target's attribute level, i.e. deterrence level, depreciates below this setting, a target will deter. Within a single run, like threats will react the same. For example, in a single run, all neutral targets will have the same deterrence level threshold regardless of location or speed.

D.   DESIGN OF EXPERIMENT

This thesis seeks to utilize a space filling design in order to capture all possible reactions of threat targets and effects of the non-lethal capabilities. A space filling design refers to thorough coverage of the many possible combinations of initial inputs. This fidelity allows the analyst to determine which factors have the greatest effect on the outcomes with a high level of confidence.

To completely cover a design space, an analyst could use a gridded or full factorial design. These designs consider every possible combination of variable input parameters. For this research, there are a total of 33 input variables of interest. If the scenario explored only two levels (high and low) per variable, the simulation would require 2^{33} (# Levels$^{\text{\# Factors}}$), or 8,589,934,592, design points. If each design point is iterated a minimum of 30 times for statistical validity, this design would take 4,903 centuries to execute. Table 3 illustrates the number of design points required of different gridded designs.

# factors	10 Levels 10^k factorial	5 Levels 5^k factorial	2 levels 2^k factorial
1	10	5	2
2	10^2 = 100	5^2 = 25	2^2 = 4
3	10^3 = 1,000	5^3 = 125	2^3 = 8
5	10^5 = 100K	5^5 = 3,125	2^5 = 32
10	10^10 = 10 billion	5^10 = 9,765,625	2^10 = 1,024
20	*Don't even think about it!*	5^20 = 95 trillion	2^20 = 1,048,576
40		5^40 = 9100 trillion trillion	2^40 = 1.1 trillion

Table 3.   Number of Simulation Runs Required in Various Gridded Designs (From OA4333, 2006)

One alternative is to reduce the number of input variables to be explored. However, another alternative which allows for the same amount of input variables with even more levels per variable is to use a Nearly Orthogonal Latin Hypercube (NOLH) space filling design. Developed by LtCol Thomas Cioppa, U.S. Army, at the Naval Postgraduate School in 2002, the NOLH facilitates efficient exploration of a large design space by arranging factors in an uncorrelated manner (see also Cioppa and Lucas, 2006). Applied to this research, the NOLH allows for all 33 factors to be explored on various levels (up to 40) in only 257 design points. Keeping the factors as uncorrelated as possible simplifies the task of linear regression modeling because it makes it easy to separate the impacts of different input factors on the MOEs. The strongest correlation in the NOLH developed for this research is -0.08105, which is quite low. Figure 12 depicts a scatterplot matrix of the correlations between the variable inputs used in this research. Each tiny sub-plot is a scatterplot of the levels of two different variables. The figure demonstrates both the space filling properties for quantitative factors of the NOLH and the lack of correlation between the factors.
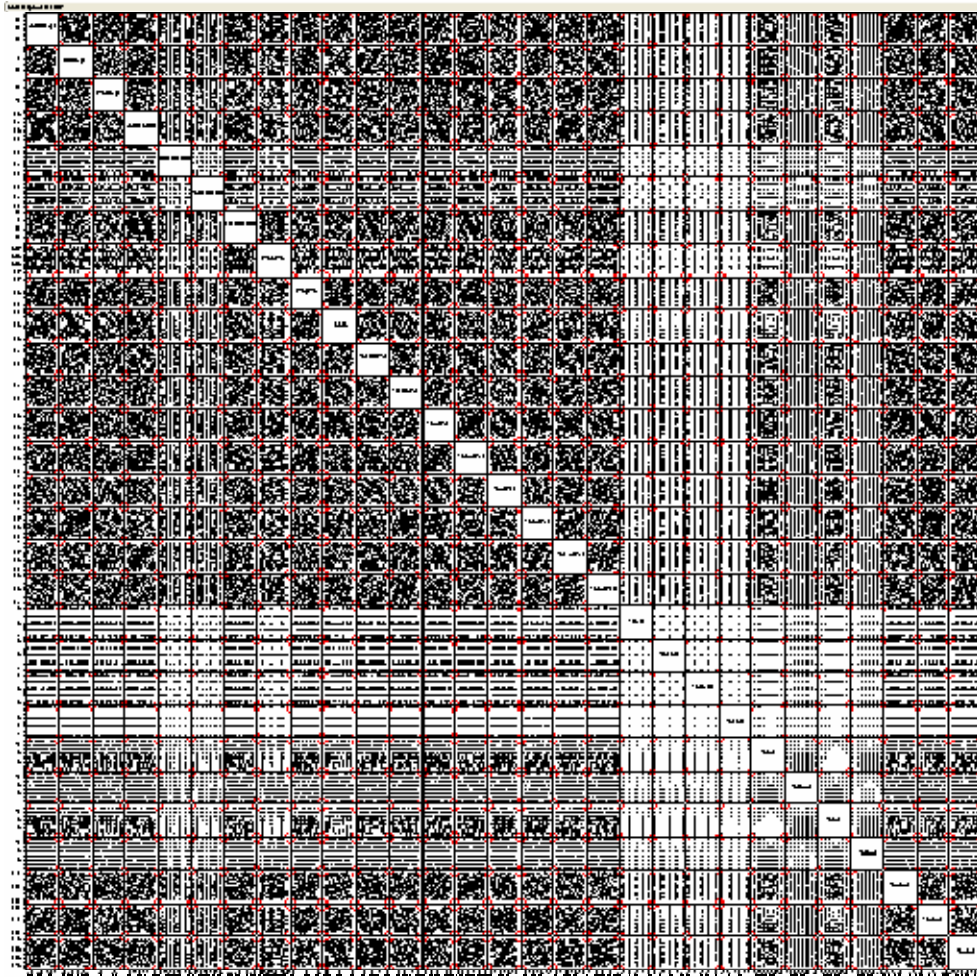
Figure 12.   Scatterplot Matrix of Factor Correlations

E.   DISTRIBUTED SIMULATION

In addition to using efficient DOEs, another way to reduce required run-time of a simulation is to network computers together to distribute different parts of a computing task across individual processors (Law and Kelton, 2000). This thesis utilizes distributed simulation in applying the NOLH DOE to the baseline scenario.

1.   Maui High Power Computing Center Simulations

Included in the Project Albert suit of tools is access to the Maui High Power Computing Center (MHPCC), which offers the ability to data farm over a large design space in a short amount of time. Using the Tiller, a program developed by Referentia Systems' Steve Upton, the PYTHAGORAS scenario file and a study file are generated in eXtensible Markup Language (XML). The study file dictates what factors are to be varied and enfolds the design of experiment to be executed. MHPCC takes these files,

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partitions the work over several computers, and runs the experimental design. Once the job is complete, MHPCC personnel zip the output and e-mail it back to the user in one consolidated file. This leads to significant time savings over other methods (Michel, 2006).

a. Debugging Experiment

The initial debugging design included the factors from Table 2 with two exceptions. First, the six 'attribute vulnerability' factors were not included (at the time, an earlier version of PYTHAGORAS was being used that did not include these modeling capabilities). Second, the hierarchy of threats had not yet been built into the scenario. Therefore, instead of three color vulnerability factors (applied to threat categories I-III), there were four factors (applied to the two hostile and two neutral threat classes). With 23 total factors, the NOLH spreadsheet tool, created by Dr. Susan Sanchez (NOLHDesigns.xls, 2006), generated a NOLH design yielding 257 design points or excursions. Using the MHPCC, each excursion was replicated 30 times, yielding 7710 data points. This initial design provided insight into the inner workings of the model, the NOLH, and the interface with MHPCC. Several scenario enhancements resulted from the debugging design.

b. Exploration Experiment

Prior to the exploration experiment, Northrop Grumman released the current version of PYTHAGORAS (Version 1.10). Included in this update was the attribute modeling capability (see Pythagoras manual (Bitinas et al., 2006) for complete list of updates and new feature descriptions). Table 2 depicts all 29 factors applied to the NOLH spreadsheet tool for this design.

Additionally, a technique called 'lockstepping' was used to alter several factors and create three new factors. Lockstepping involves creating input parameters for a variable from a derivative of another variable's input parameters. For the final design, three lockstepping processes were applied:

- The 'OD red radius ratio' and the 'WM red radius ratio' both represented proportions of other factors. For input into the PYTHAGORAS model, both were converted back to integer values.

- The two hostile and two neutral target color vulnerability inputs were derived from their respective instance, speed, and category-based color vulnerability input values.

- The second hostile target group's 'alpha less than value' was lockstepped to equal the first hostile target's input value. Similarly, the second neutral target and the neutral fishing target's 'alpha less than value' were lockstepped to equal the first neutral target's value.

The iteration level for each excursion was increased to 100, yielding 25,700 data points. Although this design produced plenty of data and some interesting results, not all of the MOEs could be extracted with enough fidelity to answer the research questions. The PYTHAGORAS model allows for two main types of output from each simulation run: 1) end-of-run MOEs and 2) time-series MOEs. Due to the high volume of data produced with the time-series MOE's, this time-series MOEs are not available when using MHPCC. The end-of-run MOEs produced with this design using MHPCC are suitable for initial analysis with all threats combined into a single group. However, this research also calls for further analysis of each individual threat class. Since time-series MOEs are available when conducting a batched run locally, this author decided to conduct a second set of experiments in order to capture the remaining MOEs of interest.

2.   Locally Paralleled Simulations

Within the PYTHAGORAS directory is a file called PythEng.bat. This file allows the user to setup and execute multiple simulation runs from the command line of a local computer (Bitinas, 2006). The PythEng.bat file allows the user to output the time-series MOE files in addition to the end-of-run MOE files.

A scripting program written in Ruby, an object-oriented programming language, automated execution of the PythEng.bat across each design point (see Appendix B). The decision to use Ruby vs. other object-oriented languages was based on its availability and compatibility. Ruby is open source and freely available for both development and deployment. Ruby in not restricted to a single platform or vendor, but can be run under Unix or Linux, Microsoft Windows, or specialized systems such as BeOS (*What is Ruby*, 2006).

a. Test Experiments

The test experiment consisted of running the first three design points with two iterations. The purpose of this small experiment was to validate the sequence and execution of the Ruby script designed for this simulation. After debugging for errors, the experiment was run a second time using two computers, ten design points (or excursions) each computer, and 100 iterations each excursion. In addition to successfully executing the Ruby scripts, this experiment provided initial run-time performance for optimal allocation of work during larger runs.

b. Final Experiment

The full design of 33 factors, 257 design points, and 100 iterations per design point was run on the same two computers. One computer handled 100 design points while the second, newer, computer tackled 147. After approximately three days of continuous run-time, the complete output detailing the MOEs on each individual target vessel was available and ready for analysis.

3. Data Extrapolation

When using the time-series MOE's, a separate file is generated for every run. Using VBA code (see Appendix C) and Microsoft Excel, all 25,700 individual files were compressed and concatenated into one composite data set.

F. SUMMARY

The experimental designs described in this chapter, used in conjunction with the computing power of distributed simulations, yield a large amount of detailed information from the simulation model. By implementing this analysis methodology, the resultant output is directly applicable in answering the research questions. The next chapter explores the analysis of this output, and what insight it brings to the questions at hand.

IV. DATA ANALYSIS

> For in this modern world, the instruments of warfare are not solely for waging war. Far more importantly, they are the means for controlling peace. Naval officers must therefore understand not only how to fight a war, but how to use the tremendous power which they operate to sustain a world of liberty and justice.[§]
>
> Admiral Arleigh Burke

A. OVERVIEW

From scenario development to implementation of the simulation experimental design, the previous chapters have focused on the generation of data for useful analysis. With a huge volume of data now available, it is time to see what insight this methodology produces. This chapter briefly describes the tools used for analysis, followed by a detailed analysis of each MOE and threat class.

B. DATA ANALYSIS TOOLS

The primary software used for data analysis is JMP Statistical Discovery Software[TM]. In addition to its robust statistical applications and user friendliness, JMP dynamically links statistics with powerful graphic visualizations (*JMP*, 2006).

1. Regression Models

a. Mixed Stepwise Regression

With 33 input variables, generating a model including interactions for a given MOE can be tedious. Therefore, stepwise regression is used as an approach to selecting a subset of the input variables when there is little theory to guide in the selection of terms (*Stepwise Regression*, 2006). The type of stepwise regression selected for this research is mixed, where the statistical software package alternates forward and backward stepwise regression until the remaining terms are significant.

[§]Arleigh Burke, (1961). *Famous Navy Quotes.* Retrieved September 4, 2006 from http://www.history.navy.mil/trivia/trivia02.htm.

b. *Standard Least Squares Linear Regression*

After stepwise regression is used to select a model of interest, the model is fit to a linear regression using standard least squares. Once fit, three statistics are examined to determine the goodness and applicability of the model. These are the adjusted R^2, the F-test statistic, and Student's t-test statistic.

The adjusted R^2 estimates the proportion of variation in the response variable that is explained by the predictor variables and not random 'noise' or error. The purpose in using the adjusted R^2 instead of the regular R^2 value is to make the model more comparable against models with a different number of predictor variables, and therefore different degrees of freedom (*A Multiple Regression*, 2006).

An Analysis of Variance (ANOVA) of the data is performed to determine if the relationship between the predictors and the response variable is statistically significant. The resultant F-test statistic and its associated p-value reveal, for a defined confidence level, that at least one of the predictors explains the response variable better than the null model. For this and all follow-on analysis, the confidence level selected for ANOVA analysis is 95%, meaning that when the F-test p-value is less than 0.05, the model is statistically significant.

Since the F-test does not specify which of the predictor variables is significant, a Student's t-test is performed on each of the variables. This determines if the variable is statistically significant, within a confidence level, in the presence of all other predictor variables. The confidence level selected for t-tests conducted in this research is 90%. Therefore, when the t-test p-value is less than 0.10, the associated predictor variable is determined to be statistically significant.

2. Recursive Partitioning

Recursive partitioning refers to the partitioning of data according to a relationship between the input variables and the output variable, creating a 'tree' of partitions. Recursive partitioning is not necessarily predictive like linear regression, but is an effective data mining technique because (*Recursive Partitioning*, 2006):

- It is good in exploring relationships without having a good prior model;

- It handles large, complex problems easily; and

- The results are very interpretable.

The simulation model for this research produces complex and highly variable data. Therefore, the recursive partitioning method effectively extracts critical knowledge, insight and trend analysis in answering the research questions where traditional regression falls short.

3. Data Visualization

Several graphical visualizations are used to compliment and highlight the statistical results. The following describes the primary visualization tools used in this research:

- Interaction Profiles – In an interaction profile, non-parallel lines demonstrate interaction between two variables. This provides a clear visualization of both the intensity and relationship of the interactions;

- Pairwise Plots – Pairwise plots are used frequently to display various relationships between two variables; and

- Partition Trees – Partition trees display the recursive partitioning as a decision tree with associated statistics.

C. OVERALL ANALYSIS

The following analyses explore the three main MOEs for all threat types combined.

1. MOE I – Deterrence Ratio

When calculating this MOE from the generated data, the hostile threat classes are not included. Since the hostile targets are modeled as suicide threats, 'deterrence' of a hostile threat is only a temporary state before its attack is resumed. Therefore, no hostile threats will have an ending status of deterred.

With the deterrence ratio defined as the response variable, stepwise regression is used to identify the predictor variables of interest. The factors eligible for the stepwise process are those that represent controllable factors. These included ranges and firing rates of the non-lethal capabilities and the ROE postures. Details about the resultant

model from the stepwise regression, performed on these seven factors, all two-way interactions between them, and all quadratic terms of the main effects, are obtained via the least-square linear regression module.

Summary of Fit

RSquare	0.263946
RSquare Adj	0.263021 **1**
Root Mean Square Error	0.195289
Mean of Response	0.590162
Observations (or Sum Wgts)	25500

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	32	348.2894	10.8840	285.3860
Error	25467	971.2598	0.0381	Prob > F
C. Total	25499	1319.5492		0.0000 **2**

Actual by Predicted Plot

Overall Det Predicted P0.0000
RSq=0.26 RMSE=0.1953

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1597881	0.009133	17.50	<.0001
AHDRange	0.0050627	0.000078	65.28	<.0001
ODRange	0.0000798	0.000106	0.75	0.4534 **3**
WMRange	-0.001739	0.000212	-8.20	<.0001
AHDFirRate	0.7139239	0.01287	55.47	0.0000
LDRedRad	-0.001426	0.000408	-3.49	0.0005
WMRedRad	-0.000309	0.000294	-1.05	0.2925
LethalRedRad	-0.001124	0.000169	-6.66	<.0001
(AHDRange-52.4471)*(ODRange-35.0157)	-0.000026	0.000007	-3.78	0.0002
(AHDRange-52.4471)*(AHDFirRate-0.33471)	-0.009843	0.000719	-13.69	<.0001
(AHDRange-52.4471)*(LDRedRad-8.67059)	0.0000368	0.000019	1.90	0.0572
(AHDRange-52.4471)*(WMRedRad-16.5843)	0.0001613	0.000014	11.13	<.0001
(AHDRange-52.4471)*(LethalRedRad-32.4235)	-0.000139	0.000011	-12.89	<.0001
(ODRange-35.0157)*(AHDFirRate-0.33471)	0.0048122	0.001166	4.13	<.0001
(ODRange-35.0157)*(LDRedRad-8.67059)	-0.000083	0.000026	-3.23	0.0012 **4**
(ODRange-35.0157)*(WMRedRad-16.5843)	0.0000863	0.00002	4.34	<.0001
(ODRange-35.0157)*(LethalRedRad-32.4235)	0.0000686	0.000014	4.81	<.0001
(WMRange-15.0314)*(AHDFirRate-0.33471)	0.0090491	0.002481	3.65	0.0003
(WMRange-15.0314)*(LDRedRad-8.67059)	-0.000222	0.000045	-4.89	<.0001
(WMRange-15.0314)*(WMRedRad-16.5843)	0.0001514	0.000033	4.53	<.0001
(WMRange-15.0314)*(LethalRedRad-32.4235)	0.0002639	0.000026	10.26	<.0001
(AHDFirRate-0.33471)*(LDRedRad-8.67059)	0.0194532	0.003207	6.07	<.0001
(AHDFirRate-0.33471)*(WMRedRad-16.5843)	0.0114066	0.002427	4.70	<.0001
(AHDFirRate-0.33471)*(LethalRedRad-32.4235)	-0.006534	0.001722	-3.79	0.0001
(LDRedRad-8.67059)*(WMRedRad-16.5843)	-0.000414	0.000066	-6.27	<.0001
(LDRedRad-8.67059)*(LethalRedRad-32.4235)	0.0001052	0.000046	2.28	0.0225
(WMRedRad-16.5843)*(LethalRedRad-32.4235)	-0.000248	0.000035	-7.01	<.0001
(AHDRange-52.4471)*(AHDRange-52.4471)	-0.000054	0.000006	-8.40	<.0001
(ODRange-35.0157)*(ODRange-35.0157)	0.0001225	0.000012	10.62	<.0001
(AHDFirRate-0.33471)*(AHDFirRate-0.33471)	-1.089064	0.175773	-6.20	<.0001
(LDRedRad-8.67059)*(LDRedRad-8.67059)	0.0004826	0.000046	10.47	<.0001
(WMRedRad-16.5843)*(WMRedRad-16.5843)	0.0002541	0.000031	8.10	<.0001
(LethalRedRad-32.4235)*(LethalRedRad-32.4235)	-0.000042	0.000018	-2.28	0.0226 **5**

Figure 13.   Final Linear Regression Model on Overall Deterrence Ratio

Figure 13 displays the statistics and model performance values obtained from the linear final regression model. Number 1 in Figure 13 reports an overall adjusted R^2 of 26.3%. This means that only one quarter of the variability observed in the deterrence ratio is explained by the predictors selected for this model. A relatively low R^2 in a model that represents a complex and highly variable real word scenario is not surprising. Number 2 in Figure 13 shows, despite the low R^2, the regression model is statistically significant given the F-test p-value. The section labeled 'Parameter Estimates' in Figure 13 lists the final factors selected as predictor variables for the model and the associated t-test statistic and p-value for each predictor. Of particular interest is the t-test conducted on OD range. Number 3 in Figure 13 shows OD range alone is statistically insignificant in affecting the deterrence ratio. However, a critical element of this research is to explore the effectiveness of the non-lethal capabilities when used as an element in a system of capabilities.   Number 4 in Figure 13 exemplifies that although OD range alone is statistically insignificant, the interaction between OD range and the ROE level for

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employing WMs is critical. Number 5 in Figure 13 shows that the quadratic terms for six of the seven main effects are statistically significant. Despite the statistical significance of the quadratic terms, including quadratic effects as potential explanatory terms had little impact on the model's explanatory power.

Of the 26 predictor terms selected for the model, 19 are statistically significant interaction terms. These relationships are more clearly visualized using JMP's interaction profiler, as seen in Figure 14. The former example of interaction between OD range and the ROE level for WM employment is highlighted by Number 1 in Figure 14. This shows that the effect of WM ROE is smaller when the value for OD max range is low, but has more effect on the overall deterrence ratio for higher values of OD max range. Figure 2 displays an opposite relationship between WMRedRad and LethalRedRad. Here, the restrictiveness of WM ROE has a greater impact on the overall deterrence ratio when there is a freer ROE for lethal force. When ROE for lethal force is highly restrictive, the ROE level for WM employment has little effect on the overall deterrence ratio.
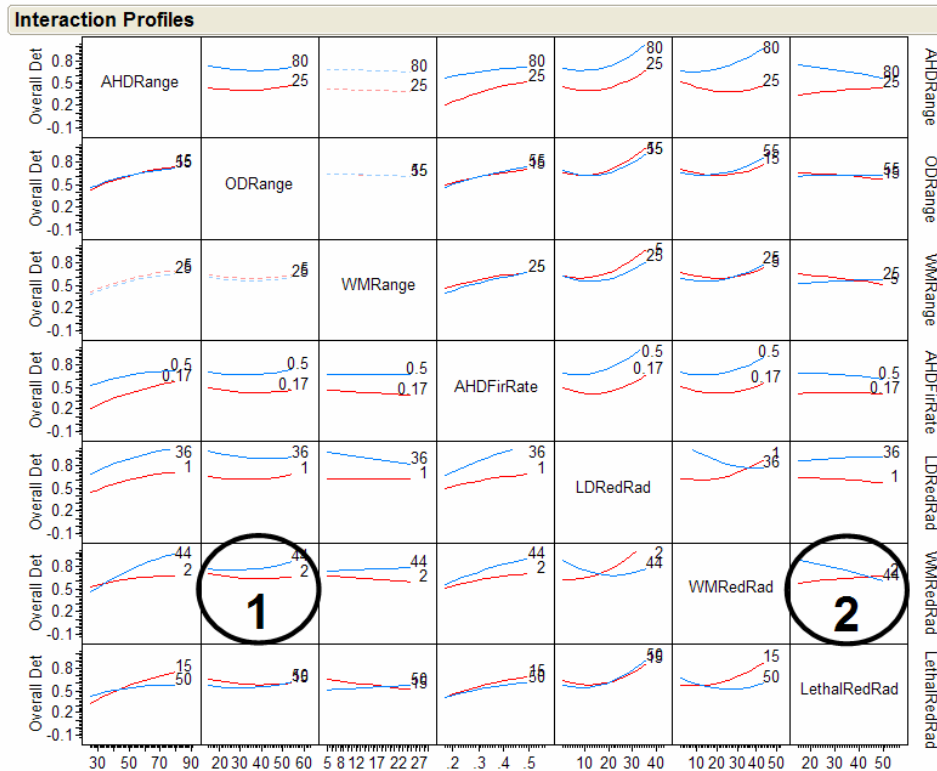
Figure 14.   Interaction Profiles of Predictor Variables

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In addition to the information provided in Figure 13, other pairwise plots are available to assess the performance of the selected regression model. Figure 15 plots the fitted deterrence ratio against the model residuals. A primary assumption underlying linear regression is that the residuals are homoscedastic, meaning that the residuals are equally varied across the observed values of the response variable. If strong 'fanning' trends are detected in this plot, then there is evidence of heteroscedasticity, and the assumption of equal variance in the residuals is not met. Figure 15 shows that there is no strong evidence of heteroscedasticity (the vertical spread between residuals is consistent across the range of predicted deterrence values) and the modeling assumption is not violated.
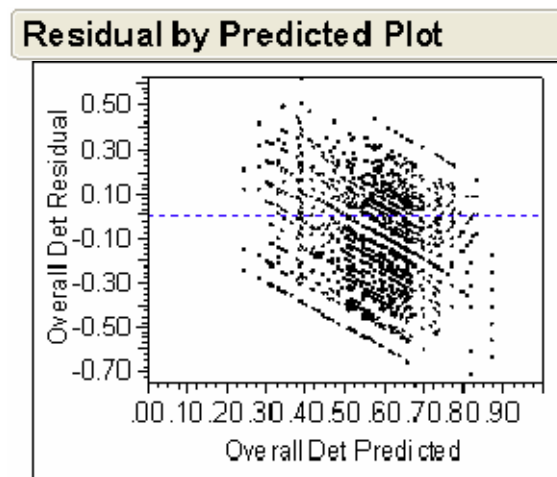
Figure 15.   Plot of Residuals vs. Fitted Variables

Another assumption of linear regression modeling is normality in the distribution of errors. Figure 16 portrays the use of visual plots to determine the normality of the residuals. The Normal Quantile plot is used to investigate whether the data exhibits the standard bell curve of a normal distribution. Since the plotted deterrence rate points closely follow a linear pattern in the Normal Quantile plot, the assumption of normality is not violated.
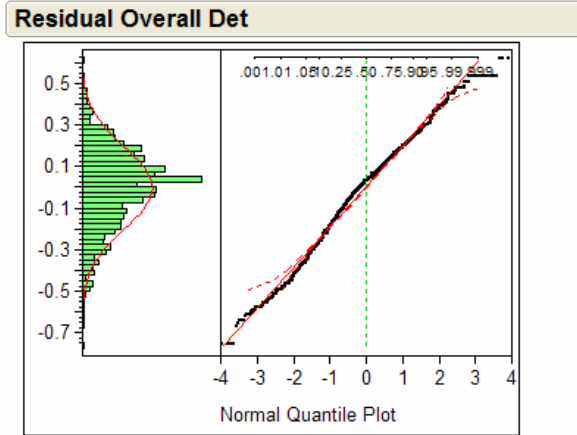
Figure 16.   Plot of Residuals of Overall Deterrence Data

Although the linear regression provides clear insight on the importance of the interaction between input variables, the large, complex scenario is not otherwise modeled well by linear regression. Therefore, we use recursive partitioning on the data. Unlike the linear regression model, the partition tree for this MOE incorporated all 33 input factors—both the controllable factors (non-lethal capabilities ranges and firing rates) and the uncontrollable factors (hostile and neutral behaviors). The first step is to recursively 'split' the data to create a partition tree. For each split, the overall value of R^2 is examined. From this information, the point of diminishing returns was used to define the appropriate number of splits. The same method is used to determine splits for all subsequent recursive partitioning.

Using four splits, the partition tree for overall deterrence rate yields an R^2 of 31.4%. Although this model captures more variability than the linear regression, the nature of the scenario continues to produce relatively low R^2 values. Figure 17 shows the partition tree representing the recursive partitioning for this MOE. Number 1 in Figure 17 shows that the most dominate factor in affecting the deterrence rate is the range of the AHD. When AHD range is greater than 975 yards (51 pixels), the overall deterrence ratio is 66%, a 15% increase over when the AHD range is less than 975 yards. Figure 2 shows that if 1) the AHD Range is less than 975 yards and 2) the channel transiting neutral target has a stubborn deterrence level threshold, then the firing rate of the AHD is

the next factor to affect the deterrence ratio. When each AHD broadcast takes less than 54 seconds (firing rate is greater than .28 shots/time step), the mean deterrence rate is 47%, vs. only 15% when the broadcast takes longer.
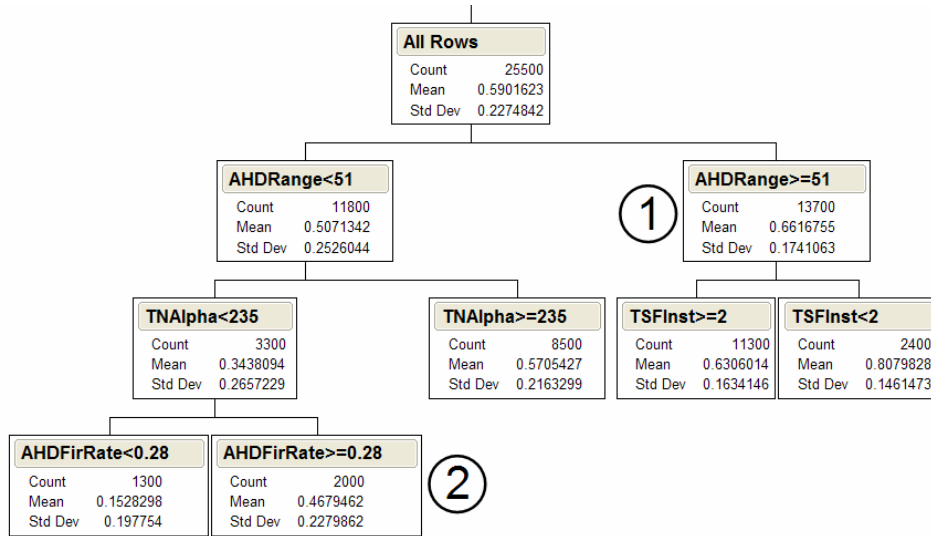
Figure 17.   Partition Tree on Overall Deterrence Ratio

Given these findings, the primary insight gleaned from this MOE is that the AHD has the most impact in deterring targets. As this is the initial non-lethal capability used in the tactic employed in this scenario, this finding is generalized to say that the first response capability has the most affect in deterring targets.

2.   MOE II – Hostile Identification Ratio

As before, stepwise regression is used to select the predictor variables of interest given hostile identification ratio as the response variable. Number 1 in Figure 18 shows an adjusted R^2 of only 6.7%. Again, although the R^2 is small, Number 2 shows that the linear regression model is statistically significant.   Number 3 demonstrates that interaction and quadratic terms are equally as important in this MOE. As before, the assumption of homoscedasticity and normality appear reasonable.
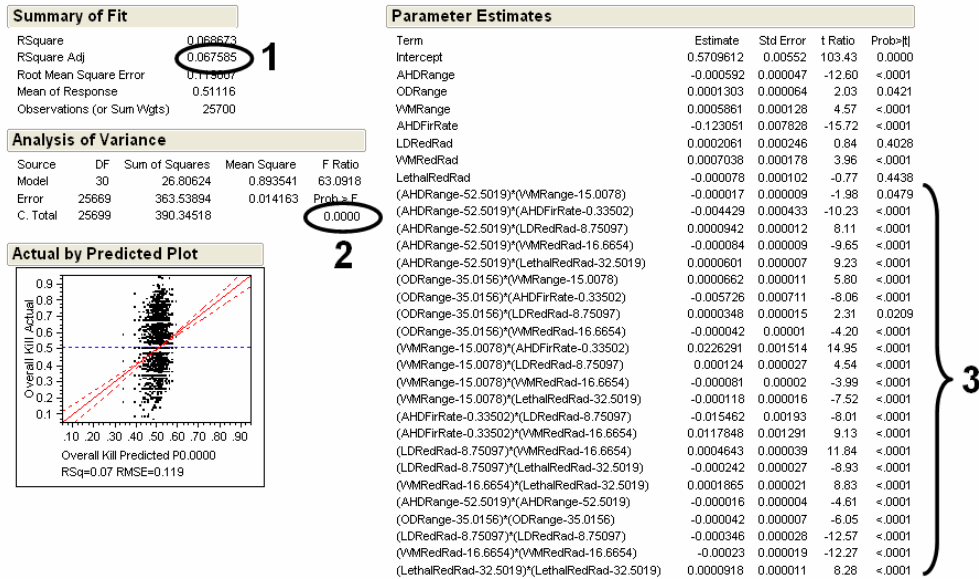
Figure 18.　Final Linear Regression Model on Overall Hostile Identification Ratio

The partition tree for this MOE sheds light on the extremely poor R^2 in the linear regression model. Figure 19 illustrates the first three splits are all factors that the blue ship has no control over, to include hostile target speed and number of suspicious fishers. The predictor variables modeled in the linear regression model do not even appear in the partition tree until many successive splits later.
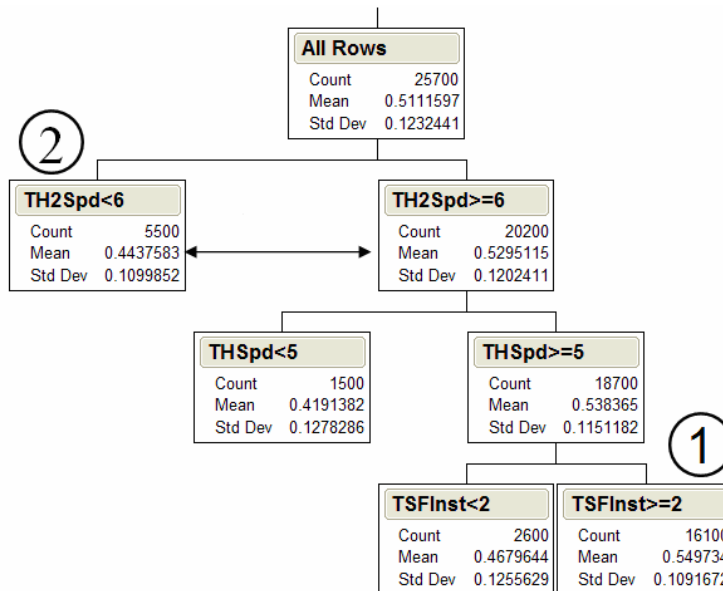
Figure 19.　Partition Tree on Overall Hostile Identification Ratio

Number 1 in Figure 19 shows the best case scenario, where if: Hostile2 target speed is greater than 14 knots (6 pixels/time step), hostile target speed is greater than 12 knots (5 pixels/time step), and the number of Suspect Fishers is greater than 2, then targets are identified as hostile 55% of the time.

Number 2 in Figure 19 represents the worst case scenario. If Hostile2 target's speed is less than 14 knots (6 pixels/time step), targets are identified as hostile 44% of the time.

The difference between the best case and worst case scenario is only 11%. Combined with a lower R^2 of only 17%, the MOE selected does not appear to give much insight towards the research questions other than the mean hostile identification ratio. Underlying statistics such as misidentification rates are explored in subsequent analyses.

3.   MOE III – Warning Zone Identification Ratio

The previous MOE only corresponds to a target identified as hostile, but not how it was identified. The scenario models two very different ways by which a target can be identified as hostile. This MOE captures those differences by recording the proportion of targets identified outside of the exclusion zone (given that a target is identified as hostile). The linear regression shows an R^2 of 26.6% and a statistically significant F-test p-value. As with the previous two MOE regressions, there is clear evidence that interactions and quadratic terms are critical. With respect to the modeling assumptions, the model is homoscedastic, but the residuals are not normally distributed. Instead, the residuals display a strong right skew. Although this assumption is violated, it does not affect the regression because the MOE selected is a mean; and therefore is not heavily dependent upon the distribution around the statistic. Figure 20 displays the model results in full detail.
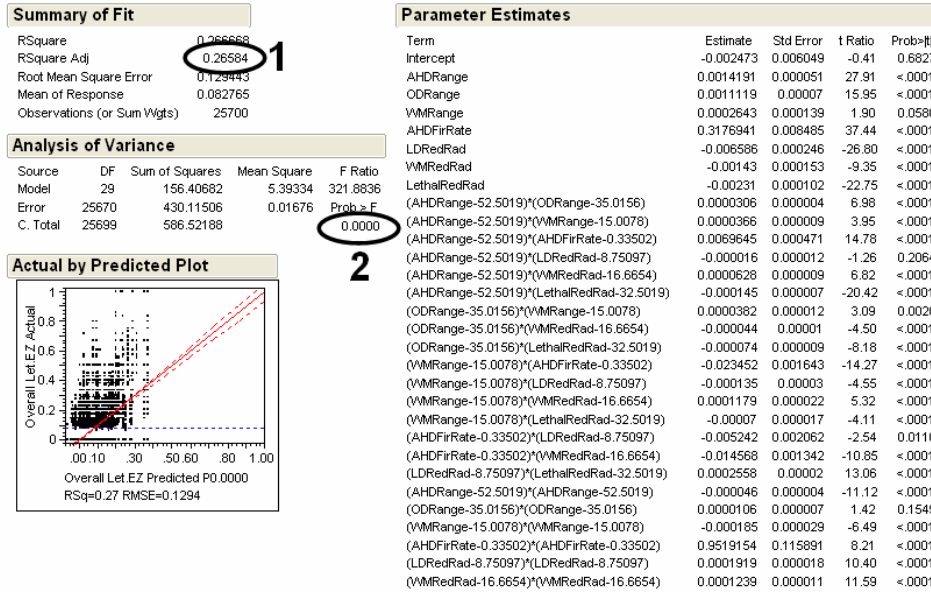
Figure 20.   Final Linear Regression Model on Warning Zone Identification Ratio

Figure 21 shows the corresponding partition tree for this MOE. The dominant input factor is the speed of the hostile target. If hostile speed is less than 14 knots (6 pixels/time step), targets are identified as hostile outside of the exclusion zone, using the non-lethal capabilities, 24.6% of the time. Otherwise, the mean identification rate outside the exclusion zone is only 3.8%—a substantial difference.
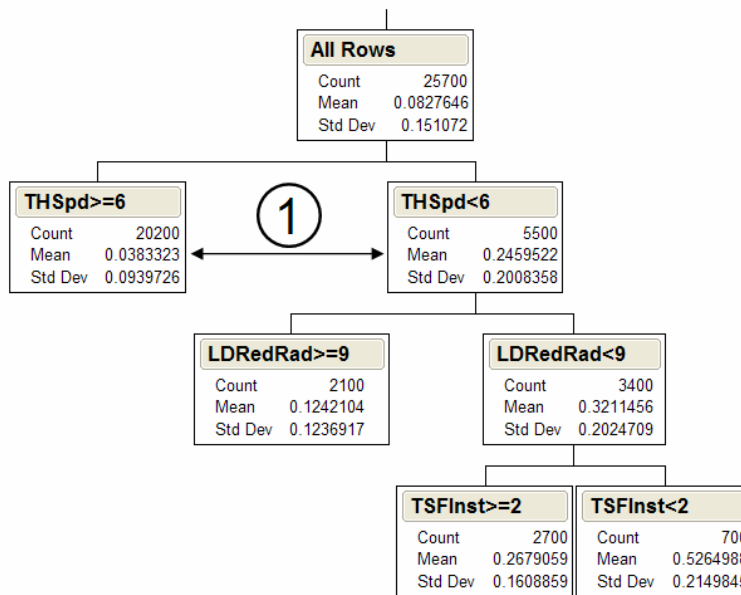
Figure 21.   Partition Tree on Overall Warning Zone Identification Ratio

The linear regression models of all three MOEs consistently establish the significance of interactions between input factors. This illustrates the importance of modeling the non-lethal capabilities as a system and not performing separate analyses for each individual component. Otherwise, the linear regression models produce little else of importance. Therefore, the remaining analyses will focus on recursive partitioning and ordinary statistics. The partition trees provided initial insight as to what factors have the most impact given any threat faced by the blue ship.

D. ANALYSIS BY THREAT CLASS

The following analyses explore the MOEs applied to each threat class. This enables more fidelity in the analysis, resulting in more detailed findings in regards to non-lethal effectiveness.

1. Hostile Targets

The MOE of interest for specific analysis of the hostile threat class is the MOE III, the warning zone identification ratio. Figure 22 displays the partition tree for the first hostile target class, which is the group that conducts the overt attack at scenario start. The R^2 for this model is 81.6%, showing that most of the variability in the MOE is explained with only 4 input factors. The first split occurs when the target speed is 14 knots (6 pixels/time step). This is consistent with the initial findings of MOE 3 using all threat classes. When looking specifically at this threat class, the impact of the inbound hostile speed is dramatic. Number 1 in Figure 22 shows the blue ship uses the non-lethal capabilities to identify the targets as hostile outside of the exclusion zone 73% of the time. However, if the inbound targets are moving faster than 14 knots, identification in the warning zone occurs only 6.5% of the time. This finding supports the research question of when non-lethal capabilities are tactically appropriate.

Number 2 in Figure 22 shows the impact of the AHD firing rate when the target speed is less than 14 knots, but ROE employment of the OD is more restrictive. In this case, hostile identification outside the exclusion zone is improved by 52% (from 37% to 89%) when the AHD broadcast takes less than 38 seconds (firing rate is greater than .39 shots/time step). This provides valuable insight into the tactical implications when using the AHD as an immediate audio warning device versus as a verbal message delivery system.

Number 3 in Figure 22 exemplifies the dominance of ROE-type factors of the non-lethal capabilities factors. For both branches of the partition tree, the next significant factor after hostile target speed is ROE restrictiveness of the non-lethal employment.
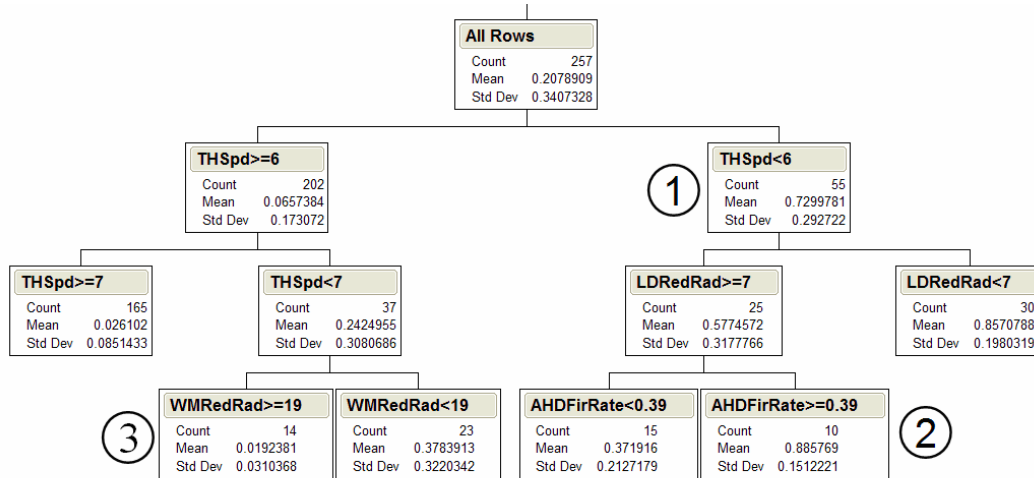
Figure 22.   Partition Tree on Hostile Identification Ratio – Hostile Target Class

The second hostile target group represents the group conducting a more covert attack from a closer range on the blue ship. Like the first target group, the model has a reasonably high R^2 of 64.8%. Number 1 in Figure 23 tells of comparative differences between the two hostile threat types where the only difference between the two is geography. The first difference noted is the count of observations observed. Because the second hostile target group attacks the blue ship towards the end of the scenario, there are iterations when the blue ship reaches its objective point before the hostile targets intercept. This is primarily a function of when the hostile targets detect the blue ship and what the hostile speed setting is for that run. Therefore, the data for the partition tree have been pre-screened to include only those data points where an interaction between the hostile group and the blue ship occur.

The second difference noted is that the mean identification ratio is 13.8%, which is 7% lower than that of the first hostile target group. As expected, this demonstrates that geography impacts the effectiveness of the non-lethal capabilities. By conducting a covert attack at a closer range, the blue ship has less reaction time. Number 2 in Figure 23 shows that unlike facing hostile targets in a more open-water environment, the

dominating factor in constrained geography is the restrictiveness of the ROE. For the tactic modeled, a quicker escalation to the use of the OD yields a 25% difference in hostile identification outside of the exclusion zone. Number 3 in Figure 23 shows that the employment time of the AHD is critical, just as it was for successfully identifying the first hostile target group.
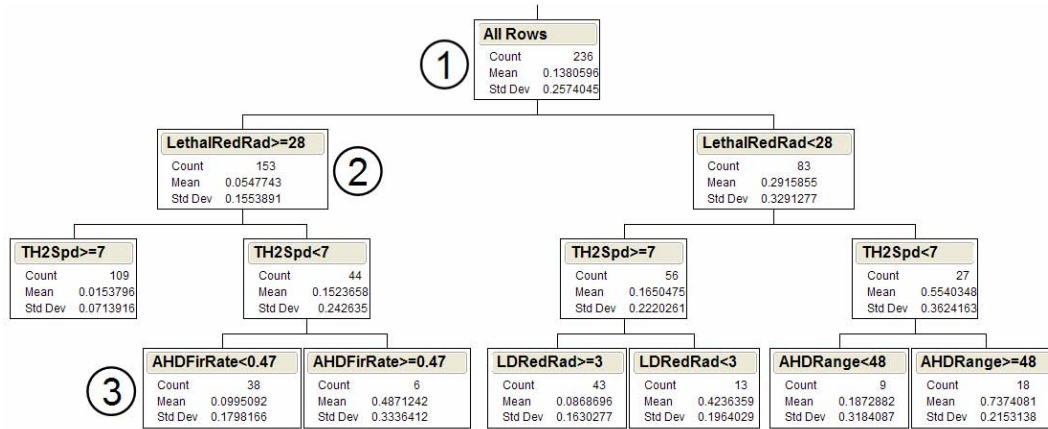
Figure 23.   Partition Tree on Hostile Identification Ratio – Hostile2 Target Class

2.   Neutral Targets

The MOE of interest for analysis of the neutral threat class is the MOE I, the deterrence ratio. Like the second hostile threat group, the data were pre-screened to analyze only data points where an interaction between the neutral target and the blue ship occur. Figure 24 displays the partition tree for the channel transiting neutral target. The probability of deterrence for the neutral target is 92.3%. When the neutral target's speed is less than 16 knots (7 pixels/time step), the neutral target is deterred 100% of the time. Although the regression tree does not show dominant effects of the non-lethal capabilities, this model demonstrates that positive action, through non-lethal employment, produces very high deterrence rates in neutral targets (regardless of the specific requirements).
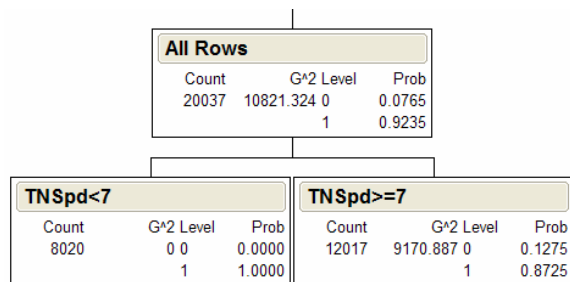
Figure 24.   Partition Tree on Deterrence Ratio – Neutral Target Class

In further examination of the data, there are 27 instances of 20,037 runs where the neutral target crosses within the blue ship's exclusion zone despite being deterred. All 27 points originate from the same design point, meaning that given 100 iterations of the same inputs, 27 runs resulted in this outcome. Reasons for this include maneuvering constraints of the neutral target and the timeliness of the target's deterrence. There are also four instances of 20,037 runs where the neutral target is identified as hostile outside of the exclusion zone. All four points originate from the same design point of input variables. A replay of these four runs using PYTHAGORAS' playback feature showed that the hostile identification event and the deterrence event happened at virtually the same time. Of the 21,569 data points, the blue ship identified the neutral target as hostile only 0.5% of the time (118 times). These cases were generally a result of the neutral target's continued negative response to non-lethal employment and an unwillingness to deter.

The second neutral target, representing a crossing ferry in a geographically constrained area, also exemplifies the effects of geography on the effectiveness of the non-lethal capabilities. Figure 25 shows a probability of deterrence of 82.7%, almost 10% less than that of the first neutral target. Number 1 in Figure 25 shows that the factor with the most effect on the deterrence rate is the range of the AHD. When the AHD range is greater than 973 yards (55 pixels), deterrence probability is 94%. However, for lesser ranges of the AHD, the probability is reduced to 72.7%. This result is consistent with the overall analysis of MOE 1, showing that the requirements of the first response capabilities are critical. This also brings specific tactical insight into the use of the AHD. If the weather supports AHD max effective range past 1,000 yards, the AHD is a very

effective first response non-lethal capability. However, if performance range of the AHD is degraded due to inclement weather conditions, such as high winds, the AHD is not as effective as a first response capability.
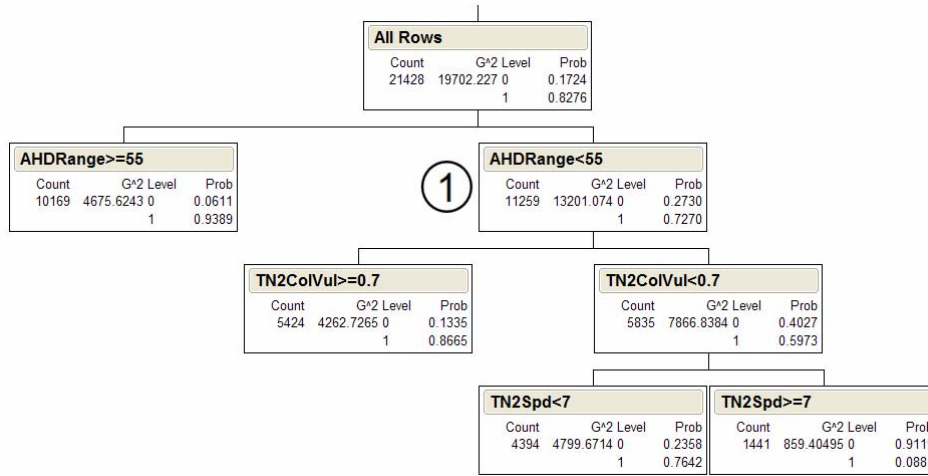
Figure 25.   Partition Tree on Deterrence Ratio – Neutral2 Target Class

Like the first neutral target, further examination of the data is conducted. There are 460 instances where the neutral target crosses within the blue ship's exclusion zone despite being deterred. This is respectably more than the 27 observed with the first neutral target and is attributed to the maneuvering restrictions of the second neutral target. Despite being deterred, the ferry neutral often has no where to run to if caught between the blue ship and land. There are 14 instances where the neutral target is identified as hostile outside of the exclusion zone, also all from the same design point. As before, a random sampling of these 14 instances showed that the hostile identification event and the deterrence event happened at virtually the same time. Of the 25,123 data points, the blue ship identified the neutral target as hostile only 0.7% of the time.

3.   Loitering Targets

The final analyses explore the mix of two threat groups loitering in the same geographic area, specifically a choke point. Figure 26 shows the partition tree of the deterrence ratio of the neutral fishing targets. Number 1 in Figure 26 displays the first split in this partition. Unlike previous analyses, the factor with the most effect is the deterrence threshold of the neutral fishers. Number 2 in Figure 26 shows when neutral fishers have high deterrence level thresholds, the factor of most significant impact is

again AHD range. With these slower moving targets, the performance threshold of the AHD is 750 yards (43 pixels). At ranges greater than 750 yards, the deterrence rate is 77%, compared to only 37.5% for lesser ranges. Number 3 in Figure 26 shows when AHD range is less than 750 yards, the next critical factor is the employment time of the AHD. In this case, deterrence rate is improved 49% (from 11.8% to 61%) when the AHD broadcast takes less than 54 seconds (firing rate is greater than .28 shots/time step). The last two findings continue to emphasize the importance of the first response capability against neutral targets.
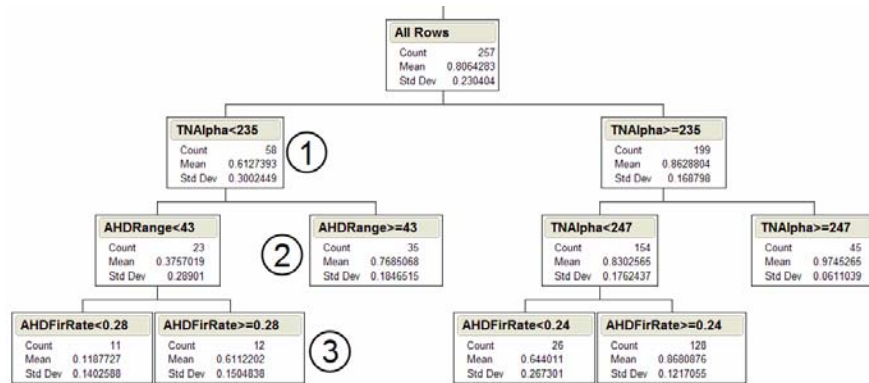
Figure 26.   Partition Tree on Deterrence Ratio – Neutral Fisher Target Class

14.4% of the neutral fishers that are deterred cross within the blue ship's exclusion zone despite being deterred. This is largely due to the even more restrictive geography combined with slower moving targets. There are no instances where the neutral fisher is both deterred and identified as hostile outside of the exclusion zone. Of the 25,700 data points, the blue ship identifies the neutral fisher as hostile outside the exclusion zone only 0.1% of the time.

Figure 27 shows the partition tree of the deterrence ratio of the suspect fishing targets. Like the neutral fishing targets, Number 1 in Figure 26 shows the factor with the most effect is the deterrence threshold. Number 2 depicts that when the suspect fishers are easily deterred, the speed of the first response capability is more important than the range. This is expected since the suspect fishers do not attack the blue ship until well

within the max range of the AHD. For this situation, deterrence rate is improved 40% (from 10% to 50%) when the AHD broadcast takes less than 42 seconds (firing rate is greater than .36 shots/time step).
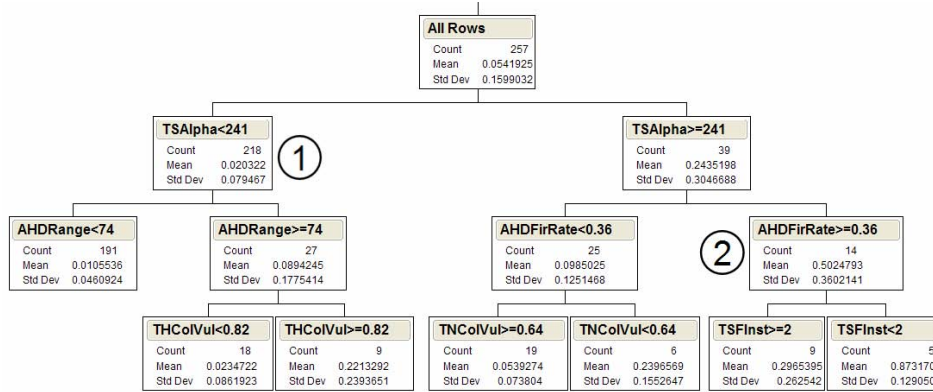
Figure 27.   Partition Tree on Deterrence Ratio – Suspect Fisher Target Class

Overall, the suspect fishers penetrate the blue ship's exclusion zone 95.4% of the time. When looking at MOE 3, the blue ship identifies the suspect fishers as hostile outside of the exclusion zone only 4 times of 25,065 observations. Combined with the results of the analyses of the neutral fishers, two very important conclusions are drawn. First, based on the deterrence rate of the neutral targets and the hostile identification rate of the suspect targets, the application of non-lethal capabilities is extremely effective in separating threats from non-threats in a homogenous group of threats. Second, based on the percentage of both neutral and suspect fishers that penetrate the exclusion zone, the counter-personnel non-lethal capabilities modeled in this research are not sufficient when used alone in order to deter loitering targets in a chokepoint.

E.   SUMMARY

In this chapter, application of validated statistical tools has been demonstrated to successfully conduct data analysis on several MOE and threat class combinations. The primary findings discovered from the analysis are as follows:

- The employment of non-lethal capabilities is extremely effective when used to identify threats from non-threats in an ambiguous situation.

- Inbound speed is the critical factor in identifying and engaging inbound hostile threats outside of the exclusion zone.

- The number of inbound targets has little to no impact on identification and engagement rates of hostile targets.

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- The first response non-lethal capability is the most crucial in deterring non-suicidal targets.

- The AHD is significantly more effective when employment time is less than 30 seconds against hostile targets and 1 minute for neutral or loitering targets.

- When used alone, counter-personnel non-lethal capabilities fail to deter loitering targets who attack when within close proximity

The following chapter links these findings back to the primary research questions and discusses their impacts.

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V.   CONCLUSIONS AND RECOMMENDATIONS

> Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.**
>
> <div align="right">Sir Winston Churchill</div>

A.   RESEARCH SUMMARY

This research began with questions. It is time to return to those questions, tie the corresponding analysis findings to them, and determine what insight can be gained. The research questions originally stated in Chapter 1 are reproduced below, but now followed by the applicable results obtained from this research.

What non-lethal capabilities are required in a maritime force protection environment in order to effectively determine intent and/or deter suspicious small vessels? This research explored this question against a multitude of threat-types, different geographies, and varying conditions. As such, no singular answer is appropriate. Instead, multiple insights are gained for all possible environments. Therefore, this primary question is addressed in each of the follow-on discussions to the sub-questions below.

In what region of conditions are non-lethal capabilities tactically appropriate? The effectiveness rates of identification and deterrence are highly sensitive to the application of the first response capability and the timeliness in employment of subsequent capabilities. If the speeds of the incoming targets are less than 14-16 knots, the tactic modeled is effective. A 39% increase in effectiveness is observed in the worst case scenario (suicidal hostile target in a geographically constrained region) when the employment time of the AHD is kept below 30 seconds. When inbound speeds are higher, alternate tactics and capabilities must be explored.

What, if any, are the major differences given varying geographic constraints? For both hostile and neutral targets, constrained geography resulted in lower identification and deterrence rates. Any warfighter knows that limited geography

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**Winston Churchill, (1942). *Classic Quotes.* Retrieved September 7, 2006 from http://www.quotationspage.com/quote/24921.html.

translates into reduced prosecution time. The specific insight gained through this research for a constrained geography environment is:

- The effectiveness of the AHD must exceed 975 yards.
- Effectiveness is extremely dependent on a relaxed ROE for the OD and WM.
- If these two conditions cannot be met, a different tactic is required.

What requirements are needed of non-lethal capabilities in order to effectively separate threats from non-threats in a homogeneous group? The first necessary task when facing a group of mixed targets is to separate the threats from the non-threats. Within the loitering targets, the neutral targets were identified as non-threats 74% of the time while the suspect fishers were recognized as threats 95.4% of the time. The most critical factor in achieving these levels of effectiveness was simply the use of the non-lethal capabilities in accordance with the modeled tactic. Meaning, the specific requirements of the non-lethal capabilities did not cause drastic variations in the results. The fact that proactive non-lethal force was applied, regardless of specific ranges and firing rates, proved extremely effective in separating threats from non-threats.

Conversely, the sole use of counter-personnel non-lethal capabilities in a choke point filled with multiple threat types did not prove effective for deterrence. Neutral fishers were deterred 80.6% of the time, however this dropped significantly to 37.5% when the AHD range was less than 750 yards. A critical finding was that if the AHD range is less than 750 yards, the firing rate should be kept below one minute in order produce the highest possible deterrence rate. Deterrence of the suspect fishers, which are the vital vessels to discourage, occurred only 5.4% of the time. Not surprisingly, this result mandates the necessity of picket boats and counter-materiel non-lethal capabilities for this environment.

Is a multi-agent simulation (MAS) an appropriate means to represent and analyze a ship's ability to determine intent and use continuum of force? Yes. The flexibility inherent in MAS, and particularly within the PYTHAGORAS model, has provided the

framework necessary to answer the previous questions. PYTHAGORAS' capacity to quantify and model elements such as ROE, fear, aggressiveness and influence, has been crucial in producing useful and applicable insight for a complex problem.

B. POTENTIAL FOLLOW-ON RESEARCH

As shown in this research MAS, efficient experimental designs and high power computing are appropriate for a broad scope of analysis in the realm of non-lethal capabilities and maritime force protection. The following recommendations are provided for areas of research which could benefit from the data farming methodology applied to this thesis.

1. Requirements

This thesis identified situations when targets are not effectively deterred using only counter-personnel non-lethal capabilities. Current doctrine employs small boats to be used as pickets to physically deter inbound vessels. Additionally, counter-materiel non-lethal capabilities are also being developed in the maritime environment. This research successfully modeled non-lethal capabilities modeled as a system. Recommended future efforts would be the expansion of this system using the same scenario to include counter-materiel capabilities and picket boats.

2. Tactics

One specific tactic, adapted from current Navy tactics, was modeled in the scenario. This research identified performance conditions in which the modeled tactic was not effective. The methodology used in this research can easily be used to conduct a comparative analysis of multiple tactics. By creating a set of scenarios where each represents a unique tactic, the scenarios can be compared to determine the most effective tactic(s) for each situation.

3. Vulnerability Assessments

As demonstrated, geography is a critical factor in the force protection of the blue ship. This methodology allows a port or chokepoint to be exhaustively searched to determine the most sensitive geographical points of vulnerability. Since real world maps, charts or satellite photos can be overlaid into the PYTHAGORAS model, construction of

a vulnerability-based scenario for any place in the world can be accomplished quickly. Future work should include application of this methodology to assist planners in port integrated vulnerability assessments prior to a ship's arrival.

4. Alternate Mission Objectives

The use of non-lethal capabilities is by no means limited to an entering port force protection scenario. The application of this methodology would be extremely relevant for analysis of alternate missions, such as straits transits and maritime interdiction missions.

5. Refined Input Parameters

As seen in the deterrence of the neutral fishers, the most significant factor was the deterrence level threshold, or willingness of the targets to deter. Since no data exists on these values, the experiment ranged across a wide variety of possibilities. As non-lethal capabilities become fielded, and real-world data is collected on these behavioral variables, future analyses can incorporate more refined behavior inputs or explore the reasonableness of these input parameter ranges.

C. RESEARCH IMPACT

Using the data farming methodology to answer the research questions outlined in this thesis is only the first step. The next level of insight is reached by understanding the applicability of this research. The following outlines the impact of this research and follow-on initiatives in the fielding of non-lethal capabilities for maritime missions.

Focuses Capability Requirements - This research uses *analytic rigor* to compliment subject matter expertise in effectively defining requirements for three pending maritime capabilities. Moreover, this research is the first to evaluate the requirements needed for an effective *system* of complimentary non-lethal capabilities.

Validates Tactics - Current Navy Tactics, Techniques and Procedures for anti-terrorism/force protection include only current capabilities. This research analyzes the integration of imminent capabilities into current tactics *prior* to acquisition, thereby providing warfighters with updated tactics as soon as capabilities are released. Included is an analysis of tactical effectiveness given varying rules of engagements, covering any geo-political situation.

Revolutionizes Vulnerability Assessments - Navy doctrine requires examination of likely enemy courses of action and friendly counteraction when conducting anti-terrorist/force protection planning. Current tactical-level wargaming efforts include table top discussions, which generally cover only a few possible courses of action. This thesis leverages high power computing to evaluate virtually *any possible* interaction with multiple threat-types, thereby generating a robust port vulnerability assessment. The methodology and model used in this research are quickly altered to support any port or choke point geography.

In summary, this research examines newly fielded or not-yet-fielded technologies, meaning little performance data exists. Secondly, this research tackles complex interactions, including critical human factors, in emulating an intricate, real-world scenario. Lastly, this research attempts to capture and make sense of the multitude of possible outcomes. George E. P. Box said, "All models are wrong, but some are useful" (Box, 1979). Despite the initial limitations and complexities, this thesis produces valuable insights through application of proven operations research tools and techniques. However, this is nothing but a beginning. Through continued application of this work across the spectrum of non-lethal applications in maritime operations, we considerably enhance our efforts to preserve the freedom of the seas and ultimately, to bring our sailors safely home.

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APPENDIX A. PYTHAGORAS COLOR COMPARISON TOOL

PYTHAGORAS uses red-green-blue (RGB) color spectrum to differentiate 'sidedness' or affiliations in a given scenario (see the PYTHAGORAS manual for further detail). This approach provides nearly unlimited flexibility in assigning multiple-sided forces and their relationships to one another. Because a user can quickly lose track of who is affiliated with whom, the PYTHAGORAS software package includes a Microsoft Excel document that allows the user to create the affiliations as he or she would in the PYTHAGORAS GUI, and then quickly determine the resultant relationships based on these inputs.

Agent Name	Red	Green	Blue	Unit				Friendly				Enemy			
				Col Rad	Use Red	Use Grn	Use Blue	Col Rad	Use Red	Use Grn	Use Blue	Col Rad	Use Red	Use Grn	Use Blue
BlueAHD	0	0	255	3	0	0	1	0	0	0	0	1	1	0	0
BlueOD	0	0	255	3	0	0	1	0	0	0	0	1	1	0	0
BlueWM	0	0	255	3	0	0	1	0	0	0	0	3	1	0	0
BlueLethal	0	0	255	3	0	0	1	0	0	0	0	6	1	0	0
TargetNeutral	1	255	0	0	0	0	0	0	0	0	0	250	0	0	1
TargetSuspect	3	255	0	0	0	0	0	0	0	0	0	250	0	0	1
TargetHostile	6	255	0	0	0	0	0	0	0	0	0	250	0	0	1

Figure 28.   Sidedness RGB Inputs for PYTHAGORAS Scenario

Figure 28 displays the sidedness RGB levels inputted into the PYTHAGORAS scenario for this research. The first four agents listed represent the three non-lethal capabilities and the lethal capability of the blue ship. The remaining three listed agents do not represent an actual target, but an identification state of an inbound target. Independent of its ground truth identification, the blue ship will always hold targets in one of these three states.

	BlueAHD	BlueOD	BlueWM	BlueLethal	TargetNeutral	TargetSuspect	TargetHostile
BlueAHD	--	UNIT	UNIT	UNIT	ENEMY	ENEMY	ENEMY
BlueOD	UNIT	--	UNIT	UNIT	ENEMY	ENEMY	ENEMY
BlueWM	UNIT	UNIT	--	UNIT	ENEMY	ENEMY	ENEMY
BlueLethal	UNIT	UNIT	UNIT	--	ENEMY	ENEMY	ENEMY
TargetNeutral	ENEMY	ENEMY			--		
TargetSuspect	ENEMY	ENEMY	ENEMY			--	
TargetHostile	ENEMY	ENEMY	ENEMY	ENEMY			--

Figure 29.   Agent Affiliations for PYTHAGORAS Scenario

Given the inputs, the PYTHAGORAS color comparison tool automatically generates the associations of the listed agents to one another. Figure 29 displays the

affiliations of this thesis. An agent can 'see' another agent in one of four ways: Unit, friend, enemy or neutral. In this example, the AHD and OD see all targets as enemy, meaning all targets are eligible to be engaged with AHD and OD non-lethal capabilities. WMs will only be employed against targets identified as suspect or hostile, while lethal force will only be used against hostile targets.

The targets view all blue assets as 'enemy.' This does not mean that every target type attacks the blue ship. Several subsequent decision rules invoked when an agent interacts with another agent are based on the affiliation between the two. Therefore, the categorization of 'enemy' is used to define subsequent sensing and movement triggers. For example, when a neutral target is deterred, its movement desire is changed to move away from the nearest 'enemy,' which is defined in Figure 29 as the blue ship. The blank spaces relate to an affiliation of neutral. The neutral association of all targets to one another is based on the initial assumption that all agent classes move, decide and engage independently from one another.

APPENDIX B. RUBY SCRIPT FOR DATA FARMING

As discussed in Chapter III, Ruby scripting code is used to implement the NOLH DOE in a distributed simulation. The script serves to accomplish 5 main tasks:

1) Take the appropriate design point from the NOLH.xls spreadsheet.

2) Update the baseline PYTHAGORAS XML scenario file with the current design point values, taken from the NOLH.xls spreadsheet.

3) Update a text input file to be used to execute the Pythagoras batch engine. The input file includes all information needed to run the Pyth.Eng.bat including seed number, index number, and output storage location.

4) Execute the design point in PYTHAGORAS for the desired number of iterations (designated in the input file) using the Pyth.Eng.bat file included in the PYTHAGORAS files.

5) Repeat the process for the next design point.

The specific code written to accomplish this is provided below:

Line	Code
1	File Name: FarmPyth.rb
2	#Add-in's required to manipulate XML files with Ruby
3	require "rexml/document"
4	include REXML
5	#Method to update the XML scenario file with a design point. The input parameters for the
6	current design point are passed to the method in the valueArray. Each factor is represented by
7	an element in the array. The xpath in each [ ] set represents the xpath to the specific factor in
8	the Pythagoras.xml scenario file.#
9	def updateScenarioFile(valueArray)
10	#loads the sceanio and converts it to REXML for manipulation
11	baseScenarioFile = File.new('E:\Norfolk.xml', "r")
12	baseScenarioDoc = Document.new(baseScenarioFile)
13	baseScenarioFile.close
14	
15	#updates AHDRange
16	baseScenarioDoc.elements["pythagoras/weaponList/weapon/maxRange"].text =
17	valueArray[0]
18	#updates OD Range
19	baseScenarioDoc.elements["pythagoras/weaponList/weapon[2]/maxRange"].text =
20	valueArray[1]

Line	Code
21	File Name: FarmPyth.rb
22	#Add-in's required to manipulate XML files with Ruby
23	require "rexml/document"
24	include REXML
25	#Method to update the XML scenario file with a design point. The input parameters for the
26	current design point are passed to the method in the valueArray. Each factor is represented by
27	an element in the array. The xpath in each [ ] set represents the xpath to the specific factor in
28	the Pythagoras.xml scenario file.#
29	def updateScenarioFile(valueArray)
30	#loads the sceanio and converts it to REXML for manipulation
31	baseScenarioFile = File.new('E:\Norfolk.xml', "r")
32	baseScenarioDoc = Document.new(baseScenarioFile)
33	baseScenarioFile.close
34	
35	#updates AHDRange
36	baseScenarioDoc.elements["pythagoras/weaponList/weapon/maxRange"].text =
37	valueArray[0]
38	#updates OD Range
39	baseScenarioDoc.elements["pythagoras/weaponList/weapon[2]/maxRange"].text =
40	valueArray[1]
41	#updates WM Range
42	baseScenarioDoc.elements["pythagoras/weaponList/weapon[5]/maxRange"].text =
43	valueArray[2]
44	#updates AHD Firing Rate
45	baseScenarioDoc.elements["pythagoras/weaponList/weapon/shotsPerTimeStep"].text =
46	valueArray[3]
47	#updates OD Red Radius
48	baseScenarioDoc.elements["pythagoras/sidednessList/sidedness[2]/enemy/radius"].text =
49	valueArray[4]
50	#updates WM Red Radius
51	baseScenarioDoc.elements["pythagoras/sidednessList/sidedness[5]/enemy/radius"].text =
52	valueArray[5]
53	#updates Lethal Red Radius
54	baseScenarioDoc.elements["pythagoras/sidednessList/sidedness[3]/enemy/radius"].text =
55	valueArray[6]
56	#updates TargetHostile Color Vulnerability
57	baseScenarioDoc.elements["pythagoras/agentList/agent[6]/colorVulnerability/colorVulnerabilit
58	yValue"].text = valueArray[7]
59	#updates TargetHostile[2] Color Vulnerability
60	baseScenarioDoc.elements["pythagoras/agentList/agent[7]/colorVulnerability/colorVulnerabilit
61	yValue"].text = valueArray[8]
62	#updates TargetNeutral Color Vulnerability
63	baseScenarioDoc.elements["pythagoras/agentList/agent[8]/colorVulnerability/colorVulnerabilit
64	yValue"].text = valueArray[9]
65	#updates TargetNeutral[2] Color Vulnerability
66	baseScenarioDoc.elements["pythagoras/agentList/agent[9]/colorVulnerability/colorVulnerabilit
67	yValue"].text = valueArray[10]
68	#updates TargetNeutralFisher Color Vulnerability
69	baseScenarioDoc.elements["pythagoras/agentList/agent[10]/colorVulnerability/colorVulnerabil
70	ityValue"].text = valueArray[11]
71	#updates TargetSuspectFisher Color Vulnerability
72	baseScenarioDoc.elements["pythagoras/agentList/agent[11]/colorVulnerability/colorVulnerabil
73	ityValue"].text = valueArray[12]

Line	Code
74	#updates TargetHostile Attribute Vulnerability
75	baseScenarioDoc.elements["pythagoras/agentList/agent[6]/attributeVulnerability/attributeVuln
76	erabilityValue"].text = valueArray[13]
77	#updates TargetHostile[2] Attribute Vulnerability
78	baseScenarioDoc.elements["pythagoras/agentList/agent[7]/attributeVulnerability/attributeVuln
79	erabilityValue"].text = valueArray[14]
80	#updates TargetNeutral Attribute Vulnerability
81	baseScenarioDoc.elements["pythagoras/agentList/agent[8]/attributeVulnerability/attributeVuln
82	erabilityValue"].text = valueArray[15]
83	#updates TargetNeutral[2] Attribute Vulnerability
84	baseScenarioDoc.elements["pythagoras/agentList/agent[9]/attributeVulnerability/attributeVuln
85	erabilityValue"].text = valueArray[16]
86	#updates TargetNeutralFisher Attribute Vulnerability
87	baseScenarioDoc.elements["pythagoras/agentList/agent[10]/attributeVulnerability/attributeVul
88	nerabilityValue"].text = valueArray[17]
89	#updates TargetSuspectFisher Attribute Vulnerability
90	baseScenarioDoc.elements["pythagoras/agentList/agent[11]/attributeVulnerability/attributeVul
91	nerabilityValue"].text = valueArray[18]
92	#updates TargetHostile Instance
93	baseScenarioDoc.elements["pythagoras/agentList/agent[6]/instance"].text = valueArray[19]
94	#updates TargetHostile[2] Instance
95	baseScenarioDoc.elements["pythagoras/agentList/agent[7]/instance"].text = valueArray[20]
96	#updates TargetNeutralFisher Instance
97	baseScenarioDoc.elements["pythagoras/agentList/agent[10]/instance"].text = valueArray[21]
98	#updates TargetSuspectFisher Instance
99	baseScenarioDoc.elements["pythagoras/agentList/agent[11]/instance"].text = valueArray[22]
100	#updates TargetHostile Speed
101	baseScenarioDoc.elements["pythagoras/agentList/agent[6]/speed/avgSpeed"].text =
102	valueArray[23]
103	#updates TargetHostile[2] Speed
104	baseScenarioDoc.elements["pythagoras/agentList/agent[7]/speed/avgSpeed"].text =
105	valueArray[24]
106	#updates TargetNeutral Speed
107	baseScenarioDoc.elements["pythagoras/agentList/agent[8]/speed/avgSpeed"].text =
108	valueArray[25]
109	#updates TargetNeutral[2] Speed
110	baseScenarioDoc.elements["pythagoras/agentList/agent[9]/speed/avgSpeed"].text =
111	valueArray[26]
112	#updates TargetHostile Alpha Less Than Trigger Value
113	BaseScenarioDoc.elements["pythagoras/agentList/agent[6]/triggerList/alphaLossTrigger/lessT
114	han"].text = valueArray[27]
115	#updates TargetHostile[2] Alpha Less Than Trigger Value
116	baseScenarioDoc.elements["pythagoras/agentList/agent[7]/triggerList/alphaLossTrigger/lessT
117	han"].text = valueArray[28]
118	#updates TargetNeutral Alpha Less Than Trigger Value
119	baseScenarioDoc.elements["pythagoras/agentList/agent[8]/triggerList/alphaLossTrigger/lessT
120	han"].text = valueArray[29]
121	#updates TargetNeutral[2] Alpha Less Than Trigger Value
122	baseScenarioDoc.elements["pythagoras/agentList/agent[9]/triggerList/alphaLossTrigger/lessT
123	han"].text = valueArray[30]
124	#updates TargetNeutralFisher Alpha Less Than Trigger Value
125	baseScenarioDoc.elements["pythagoras/agentList/agent[10]/triggerList/alphaLossTrigger/less
126	Than"].text = valueArray[31]

Line	Code
127	#updates TargetSuspectFisher Alpha Less Than Trigger Value
128	baseScenarioDoc.elements["pythagoras/agentList/agent[11]/triggerList/alphaLossTrigger/less
129	Than"].text = valueArray[32]
130	#writes the changes to the .xml file for implementation
131	file = File.new('E:\Norfolk.xml', "w")
132	baseScenarioDoc.write(file)
133	file.close
134	end
135	#Opens the Design of Experiment file and strips the factor names from 1st row
136	$inputFile = File.new('C:\Pythagoras\inputData.csv', "r")
137	$columnHeaders = $inputFile.readline.strip.split(",")
138	#Loop to iterate through the design points. 'X'.times represents the number of design #points
139	to be run.
140	100.times do |designPoint|
141	#Sets beginning seed and index for current design point
142	$seed = (designPoint*100) + 1
143	$index = (designPoint*100) + 1
144	#Opens old pythenginput file to change seed and index. The pythinput file feeds the
145	#PythEng.bat file the necessary inputs to run.
146	pythenginput = File.open('C:\Pythagoras\pythenginput.txt', "r+")
147	array = pythenginput.readlines
148	pythenginput.close
149	array[2] = "#{$seed}\n"
150	array[3] = "#{$index}\n"
151	#Writes new pythenginput file for current design point
152	logstream = File.new('C:\Pythagoras\pythenginput.txt', "w")
153	7.times {|i| logstream.write(array[i]) }
154	logstream.close
155	#Updates XML scenario file with current design point input parameters
156	valueArray = $inputFile.readline.strip.split(",")
157	updateScenarioFile(valueArray)
158	puts "Attempting to calculate designPoint " + designPoint.to_s
159	#executes Pythagoras (both pytheng.bat and pythenginput.txt must be in same folder as
160	#FarmPyth.rb)
161	puts `PythEng.bat < pythenginput.txt`
162	
163	print "Just finished " + designPoint.to_s
164	end
165	print "Batch Complete\n"

APPENDIX C. VBA SCRIPT FOR DATA CLEANING

As discussed in Chapter 3, a sizable amount of data cleaning was needed in order to produce a single file to be used for data analysis. The following sub-programs coded using VBA and Microsoft Excel macro recording accomplish the required data cleaning for this research.

DPIterate(): This class takes the 100 design points of the NOLH.xls spreadsheet and creates blank rows in between each design point which correspond to the number of desired iterations per design point.

```
Sub DPIterate()
'
' DPIterate Macro
' Macro recorded 8/23/2006 by Lisa R. Sickinger
' Creates rows in between each design point for iterations
'

For i = 0 To 256
   Cells(((100 * i) + 2), 2).Select ' '100' is number of iterations per run
   For j = 0 To 98 ' '98' is number of iterations per run - 2
     Selection.EntireRow.Insert
   Next j
Next i

End Sub
```

RowCopy(): This copies the input data from each design point to the newly created blank rows associated with that design point.

```
Sub RowCopy()
'
' RowCopy Macro
' Macro recorded 8/23/2006 by Lisa R. Sickinger
' Copies each design point applicable number of times
'

For i = 0 To 256
   Range((Cells(((100 * i) + 2), 2)), (Cells(((100 * i) + 2), 34))).Select
   ' '100' = number of design points
   ' '34' = number of factors + 1
   Selection.AutoFill  Destination:=Range((Cells(((100 * i) + 2), 2)), (Cells(((100 * i) + 101), 34))),
Type:=xlFillDefault
   ' '101' = number of design points + 1
   Range((Cells(((100 * i) + 2), 2)), (Cells(((100 * i) + 101), 34))).Select
Next i
End Sub
```

Consolidate(): This class takes the 25,700 individual AGB files created from the time series MOEs and consolidates them to 257 files, one for each design point. An individual file has a header with agent information, followed by 100 rows of raw data, corresponding to the output data of the 100 iterations for that design point. Because different design points have different number of agents, the program is flexible to construct the correct number of columns for each design point file.

```vba
Sub Consolidate()
'
' Consolidate Macro
' Macro recorded 8/20/2006 by Lisa Sickinger
'
'   change name of file to reflect file that starts current design point
  begDP = Cells(3, 3) ' first dp
  endDP = Cells(4, 3) ' last dp
  For dp = begDP To endDP
  Name = (dp * 100) - 99
  Workbooks.Open Filename:= _
     "C:\Documents and Settings\SEEDLab\NorfolkMOE\DP" & dp & "Output.xls"
  Workbooks.OpenText Filename:= _
     "C:\Documents    and    Settings\SEEDLab\NorfolkMOE\Norfolk_"    &    Name    &    "_Agent
ABG.AgentAlpha,Beta,Gamma" _
     , Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
     xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=False, Semicolon:=False _
     , Comma:=True, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
     Array(2, 1), Array(3, 1), Array(4, 1), Array(5, 1), Array(6, 1), Array(7, 1), Array(8, 1), _
     Array(9, 1), Array(10, 1), Array(11, 1), Array(12, 1), Array(13, 1), Array(14, 1), Array(15 _
     , 1), Array(16, 1), Array(17, 1), Array(18, 1), Array(19, 1), Array(20, 1), Array(21, 1), _
     Array(22, 1), Array(23, 1), Array(24, 1), Array(25, 1), Array(26, 1), Array(27, 1), Array( _
     28, 1), Array(29, 1), Array(30, 1), Array(31, 1), Array(32, 1), Array(33, 1), Array(34, 1), _
     Array(35, 1), Array(36, 1), Array(37, 1), Array(38, 1), Array(39, 1), Array(40, 1), Array( _
     41, 1), Array(42, 1), Array(43, 1), Array(44, 1), Array(45, 1), Array(46, 1), Array(47, 1), _
     Array(48, 1), Array(49, 1), Array(50, 1), Array(51, 1), Array(52, 1), Array(53, 1), Array( _
     54, 1), Array(55, 1), Array(56, 1), Array(57, 1), Array(58, 1), Array(59, 1), Array(60, 1), _
     Array(61, 1), Array(62, 1), Array(63, 1), Array(64, 1), Array(65, 1), Array(66, 1), Array( _
     67, 1), Array(68, 1), Array(69, 1)), TrailingMinusNumbers:=True
  Range("B2:CC4").Select
  Selection.Copy
  ' change name of active window
  Windows("DP" & dp & "Output").Activate
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
  ' change name of active window
  Windows("Norfolk_" & Name & "_Agent ABG.AgentAlpha,Beta,Gamma").Activate
  ActiveWindow.Close
  ' change i = x01 To (x+1)00
  For i = ((dp * 100) - 98) To (dp * 100)
  Workbooks.OpenText Filename:= _
     "C:\Documents    and    Settings\SEEDLab\NorfolkMOE\Norfolk_"    &    i    &    "_Agent
ABG.AgentAlpha,Beta,Gamma" _
     , Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
     xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=False, Semicolon:=False _
```

```
       , Comma:=True, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
         Array(2, 1), Array(3, 1), Array(4, 1), Array(5, 1), Array(6, 1), Array(7, 1), Array(8, 1), _
         Array(9, 1), Array(10, 1), Array(11, 1), Array(12, 1), Array(13, 1), Array(14, 1), Array(15 _
         , 1), Array(16, 1), Array(17, 1), Array(18, 1), Array(19, 1), Array(20, 1), Array(21, 1), _
         Array(22, 1), Array(23, 1), Array(24, 1), Array(25, 1), Array(26, 1), Array(27, 1), Array( _
         28, 1), Array(29, 1), Array(30, 1), Array(31, 1), Array(32, 1), Array(33, 1), Array(34, 1), _
         Array(35, 1), Array(36, 1), Array(37, 1), Array(38, 1), Array(39, 1), Array(40, 1), Array( _
         41, 1), Array(42, 1), Array(43, 1), Array(44, 1), Array(45, 1), Array(46, 1), Array(47, 1), _
         Array(48, 1), Array(49, 1), Array(50, 1), Array(51, 1), Array(52, 1), Array(53, 1), Array( _
         54, 1), Array(55, 1), Array(56, 1), Array(57, 1), Array(58, 1), Array(59, 1), Array(60, 1), _
         Array(61, 1), Array(62, 1), Array(63, 1), Array(64, 1), Array(65, 1), Array(66, 1), Array( _
         67, 1), Array(68, 1)), TrailingMinusNumbers:=True
     Range("B4:CC4").Select
     Selection.Copy
     ' change name of active window
     Windows("DP" & dp & "Output.xls").Activate
     ' change (i-x) to design point start -1
     Cells((i - ((dp * 100) - 100) + 2), 1).Select
     Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
         :=False, Transpose:=False
     Windows("Norfolk_" & i & "_Agent ABG.AgentAlpha,Beta,Gamma").Activate
     ActiveWindow.Close
     Next i
     Windows("DP" & dp & "Output").Activate
     ActiveWorkbook.save
     ActiveWindow.Close
     Next dp
   End Sub
```

Truncate(): When it is time to create the formulas needed to generate the MOEs of interest from the raw data, a problem arises when using conditional statements for an agent class type. Each agent has its class name listed followed by a number indicating the specific agent number for that run. An example is Hostile2Target (5), where the data represents the 5th agent for that run, which is of class type Hostile2. In order to perform conditional calculations for all agents of a class type, the specific agent identification number needs to be truncated. The following program truncates the agent identification from the header line of the design point file. This is done by defining the header column as delimited data where the delimiter is the first open parenthesis. Therefore, the newly formed header will include all previous information, regardless of string length, minus all text following the first parenthesis. This process is repeated for all 257 design point files.

65

```
Sub Truncate()
'
' Truncate Macro
' Macro recorded 8/27/2006 by SEEDLab
'

'
For dp = 1 To 257
  Workbooks.Open Filename:= _
    "C:\Documents and Settings\SEEDLab\NorfolkMOE\DPOutput\DP" & dp & "Output.xls"

  Rows("1:1").Select
  Selection.Copy
  Sheets("Sheet2").Select
  Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=True
  Application.CutCopyMode = False
  Selection.TextToColumns Destination:=Range("A1"), DataType:=xlDelimited, _
    TextQualifier:=xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=False, _
    Semicolon:=False, Comma:=False, Space:=False, Other:=True, OtherChar _
    :="(", FieldInfo:=Array(Array(1, 1), Array(2, 1)), TrailingMinusNumbers:=True
  Selection.Copy
  Sheets("Sheet1").Select
  Range("A1").Select
  Selection.PasteSpecial Paste:=xlPasteAll, Operation:=xlNone, SkipBlanks:= _
    False, Transpose:=True
  ActiveWorkbook.Save
  ActiveWorkbook.Close
Next dp

End Sub
```

InsertCol(): First, a clone of the first design point file is created and it is renamed "MasterOutput." This file is used to create all the MOE formulas/columns of interest. Once the desired MOE columns are created, the following code inserts new columns in each design point file that correspond to the number of MOE formula columns. These columns are added the beginning of each design point file, so that when they are later merged, the same columns will be copied from each design point file, regardless of how many columns each file contains.

```
Sub Insertcol()
'
' Insertcol Macro
' Macro recorded 8/27/2006 by SEEDLab
'

'
For dp = 1 To 257
  Workbooks.Open Filename:= _
    "C:\Documents and Settings\SEEDLab\NorfolkMOE\DPOutput\DP" & dp & "Output.xls"
```

```
   For i = 1 To 33
      Columns("A:A").Select
      Selection.Insert Shift:=xlToRight
   Next i
   ActiveWorkbook.Save
   ActiveWorkbook.Close
 Next dp
 End Sub
```

Formulas(): This program copies the formulas created in the MOE columns of the MasterOutput file and places them in the newly formed MOE columns of each design point file. The result is automatically calculated MOEs for each design point file.

```
Sub Formulas()
'
' Formulas Macro
' Macro recorded 8/27/2006 by SEEDLab
'

'

   For dp = 1 To 257

      Range("A1:AG102").Select
      Selection.Copy
      Workbooks.Open Filename:= _
        "C:\Documents and Settings\SEEDLab\NorfolkMOE\DPOutput\DP" & dp & "Output.xls"
      Range("A1").Select
      Selection.PasteSpecial Paste:=xlPasteFormulas, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
      Application.CutCopyMode = False
      Calculate
      ActiveWorkbook.Save
      ActiveWorkbook.Close
      Windows("OutputMaster").Activate
   Next dp
 End Sub
```
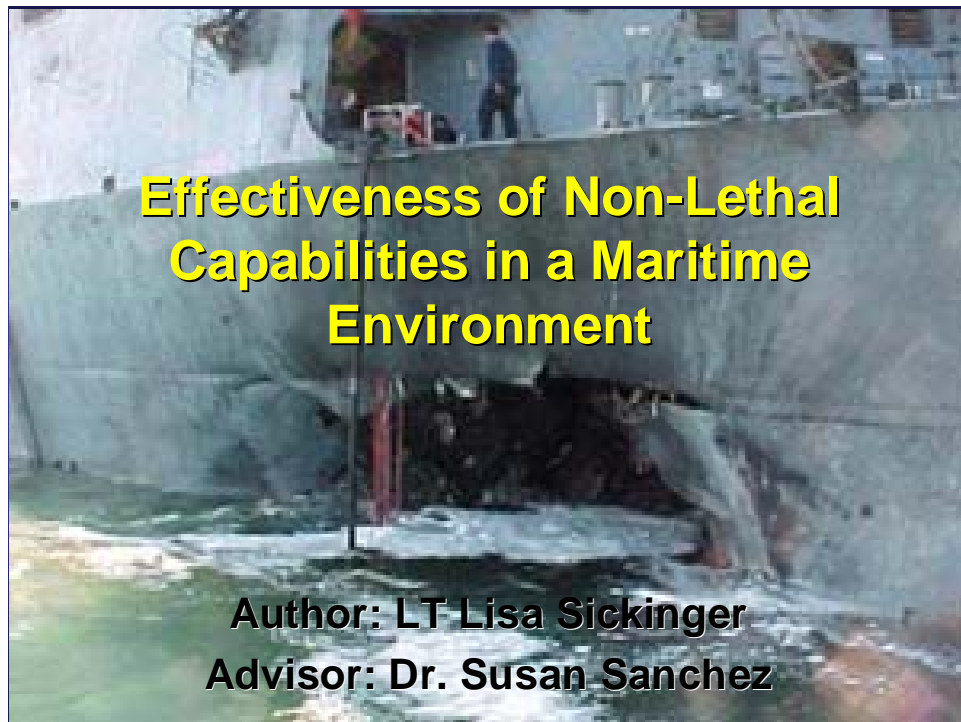
Merge(): This program copies all MOE columns from each design point file and pastes them alongside the corresponding input data created using the DPIterate and RowCopy programs. The result is a single file with 25,700 rows of data. The first 33 columns represent the input parameters while the remaining columns represent the MOE data, or output values. The file is now ready for analysis using one's favorite statistical software package.

```
Sub merge()

  For dp = 1 To 257

    Workbooks.Open Filename:= _
      "C:\Documents and Settings\SEEDLab\NorfolkMOE\DPOutput\DP" & dp & "Output.xls"
    Range("B3:AG102").Select
    Selection.Copy
    Windows("SingleOutput").activate
    Cells(((dp * 100) - 100) + 2, 35).Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
     :=False, Transpose:=False
    Windows("DP" & dp & "Output").activate
    ActiveWorkbook.Save
    ActiveWorkbook.Close
    Windows("SingleOutput").activate

  Next dp

End Sub
```

APPENDIX D. MILITARY OPERATIONS RESEARCH SOCIETY (MORS) TISDALE COMPETITION PRESENTATION

The following slides were presented to a committee of faculty at the Naval Postgraduate School for the Military Operations Research Society (MORS) Stephen A. Tisdale Graduate Research Award. This award recognizes high-quality research of immediate or near-term value to the defense of the United States and its allies. This author was one of five finalists selected for the competition based on the potential impact of this thesis work on the Department of Defense.

Effectiveness of Non-Lethal Capabilities in a Maritime Environment

Author: LT Lisa Sickinger
Advisor: Dr. Susan Sanchez

What's the Problem?
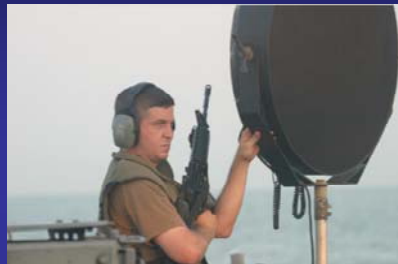
- Can We:
  - *Identify* potential threats?
  - *Determine intent* of approaching small vessels?
  - *Deter* vessels from crossing the exclusion zone?

- Do We:
  - Have the *tools* and *procedures* in place to answer these questions?

Appropriate Tools?

Optical Dazzler   **Acoustic Hailing Device**

Warning Munitions

3

Research Questions

Primary research question:

- What non-lethal capabilities are required for maritime force protection missions?

Supporting questions:

- Is Multi-Agent Simulation (MAS) an appropriate tool?

- When are non-lethal capabilities tactically appropriate?

- What are the geographical effects?

- How to identify threats from non-threats?
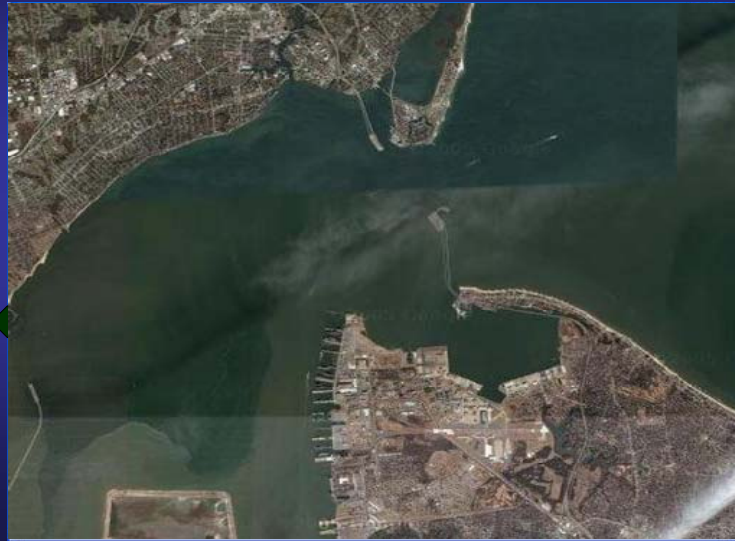
4

Methodology

- Agent Based Modeling

- "Data Farming"
  - Efficient Design of Experiment
  - Distributed Simulation

- Data Analysis

5

The Agent Based Model

Efficient Design of Experiment

	Gridded	NOLH
# of Factors	29	29
# of Levels/Factor	2	~10 (up to 40!)
# of Design Points	536870912	257
# of Runs/DP	1	100
Total CPU Time	**1021 years**	**18 days**

ROE/Training vs. Requirements
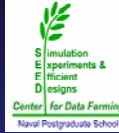
MOE: % Hostile Targets Identified (and engaged) outside of the NPEZ

ROE/Training Factors *Dominate* Requirements Factors

All Rows	
Count	257
Mean	0.2078909
Std Dev	0.3407328

THSpd>=6
Count	202
Mean	0.0657384
Std Dev	0.173072

THSpd<6
Count	55
Mean	0.7299781
Std Dev	0.292722

THSpd>=7
Count	165
Mean	0.026102
Std Dev	0.0851433

THSpd<7
Count	37
Mean	0.2424955
Std Dev	0.3080686

LDRedRad>=7
Count	25
Mean	0.5774572
Std Dev	0.3177766

LDRedRad<7
Count	30
Mean	0.8570788
Std Dev	0.1980319

WMRedRad>=19
Count	14
Mean	0.0192381
Std Dev	0.0310368

WMRedRad<19
Count	23
Mean	0.3783913
Std Dev	0.3220342

AHDFirRate<0.39
Count	15
Mean	0.371916
Std Dev	0.2127179

AHDFirRate>=0.39
Count	10
Mean	0.885769
Std Dev	0.1512221

AHDFirRate<0.34
Count	12
Mean	0.2098611
Std Dev	0.234176

AHDFirRate>=0.34
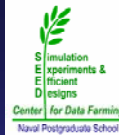| Count | 11 |
| Mean | 0.5622424 |
| Std Dev | 0.310752 |

$R^2 = 0.840$

10

Conclusions

- Hostile Targets:
  - Tactical: Tactically appropriate against targets w/ speed < 14 knots.
  - Requirements: AHD significantly more effective when used as audio warning only and not message delivery.
- Neutral Targets:
  - Tactical:
    - Geography plays an important role in deterring neutral targets.
    - The tactic modeled is significantly less effective when environmental conditions cause performance degradation of AHD.
  - Requirements: The first response weapon has the most effect.
- Loitering Targets:
  - Significantly effective in identifying threats from non-threats
  - When used alone, counter-personnel non-lethal capabilities fail to deter loitering targets who attack when within close proximity.

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The Impact

- ***Outlines Capability Requirements***
  - Compliments SME in defining requirements
  - First to evaluate capabilities as a system

- ***Validates Tactics***
  - Explores integration with current tactics early in the process
  - Assesses tactics in varying geo-political situations

- ***Revolutionizes Vulnerability Assessments***
  - Evaluates nearly any possible enemy COA
  - Exploits vulnerable areas of interest

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Who Cares?

- Naval Postgraduate School
- Joint Non-Lethal Weapons Directorate
- OPNAV N757
- Mobile Security Forces, Norfolk
- OPNAV N81
- Office of Naval Research
- Project Albert – Referentia (MCWL)
- Joint Test and Evaluation Methodology (JTEM)

13

The Final Word

Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.

– Winston Churchill

14

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