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THESIS

**EXPLORATION OF FORCE TRANSITIONS IN
STABILITY OPERATIONS USING MULTI-AGENT
SIMULATION**

by

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September 2006

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**EXPLORATION OF FORCE TRANSITIONS IN STABILITY OPERATIONS
USING MULTI-AGENT SIMULATION**

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Submitted in partial fulfillment of the
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ABSTRACT

Stability Operations have become the most prevalent mission for U.S. forces in the current global security environment. This research explores new methods to assist in determining when it is acceptable to downsize a force in a stability operation. The methodology developed provides insight into this problem by quantifying force protection risk, mission failure risk, and time in the context of the operational threat environment.

The Pythagoras Multi-Agent Simulation and Data Farming techniques are used to investigate force-level comparisons in a theoretical threat continuum based on a peacekeeping scenario similar to the Bosnian operation. The data from the simulation is used to construct simple tools for decision makers. These tools are used collectively to find the balance, according to a commander's priorities, between the conflicting issues of force protection, mission success, and time.

Two areas are identified as significant in achieving success in a stability operation. They are troop posturing and troop employment. The problem is that they are often overlooked or under emphasized. The results of this research demonstrate that posturing and employment should be considered as factors equal to force size in contributing to the goal of maximizing force presence. In addition, this research provides a vehicle to assist military planners with ways in which a stability force can maximize and maintain near continuous presence, while simultaneously minimizing the risk to the force and adhere to operational timelines.

Overall, the important conclusion is the significance of troop posture on force size transitions. As a force is downsized, it is crucial to evaluate how to maintain presence with the smaller force. This is evident by the surprising success achieved by the smallest force in the simulation. It was able to project a greater presence by utilizing small dispersed units, much like the Combined Action Platoons in Vietnam.

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LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

ABM	Agent-Based Models
ABS	Agent-Based Simulations
AOR	Area of Responsibility
CNA	Center for Naval Analyses
DMSO	Defense Modeling and Simulation Office
DO	Distributed Operations
DoD	Department of Defense
DoDD	Department of Defense Directive
DOE	Design of Experiment
DPRE	Displaced Persons and Refugees
EADS	European Aeronautic Defence and Space Company
EINStein	Enhanced Isaac Neural Simulation Toolkit
EUCOM	United States European Command
GIRH	Generic Intelligence Requirements Handbook
GUI	Graphical Users Interface
HMMWV	High Mobility Multi-Wheeled Vehicle
HQ	Headquarters
HUMINT	Human Intelligence
IED	Improvised Explosive Device
IFOR	Implementation Force
IFV	Infantry Fighting Vehicle
IPTF	International Police Task Force

ISAAC	Irreducible Semi-Autonomous Adaptive Combat
ISR	Intelligence, Surveillance, Reconnaissance
KPH	Kilometers per Hour
M&S	Modeling and Simulation
MANA	Map Aware Non-Automata
MAS	Multi-Agent Simulation
MCWL	Marine Corps Warfighting Lab
MCCDC	Marine Corps Combat Development Command
METT-TSL	Mission, Enemy, Terrain/Weather, Troops/Fire Support available, Time, Space, Logistics
MHPCC	Maui High Performance Computing Center
MOB	Main Operating Base
MOE	Measure of Effectiveness
MOOTW	Military Operations Other Than War
MOP	Measure of Performance
NATO	North Atlantic Treaty Organization
NOLH	Nearly Orthogonal Latin Hypercube
NPS	Naval Postgraduate School
OPFOR	Opposing Force
PAIW	Project Albert International Workshop
PKF	Peacekeeping Force
PKO	Peacekeeping Operations
P_h	Probability of Hit

P _k	Probability of Kill
PC	Personal Computer
QRF	Quick Reaction Force
RGB	Red, Green, Blue
RTB	Return to Base
SA	Situational Awareness
SASO	Stability and Support Operations
SBCT	Stryker Brigade Combat Team
SEED	Simulation, Experimentation, and Efficient Design
SFOR	Stabilization Force
SOP	Standard Operating Procedure
SSTR	Stability, Security, Transition, and Reconstruction
TLE	Target Location Error
TTP	Tactics, Techniques and Procedures
UN	United Nations
USD(P)	Under Secretary of Defense for Policy
USJFCOM	United States Joint Forces Command
VV&A	Validated, Verified, and Accredited

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EXECUTIVE SUMMARY

Stability Operations have become the most prevalent mission for United States forces in the current global security environment. Since the end of the Cold War, U.S. forces have participated in more Stability and Support Operations (SASO) than major combat operations. The U.S. military will continue to be engaged in many diverse and complex Stability Operations for years to come.

Until recently, Stability Operations were inferior to combat operations in the prioritization of training and equipping. In addition, the planning and research on how to execute Stability Operations had always been over shadowed by the requirements of conventional combat operations. With the issuance of DoD Directive 3000.05 in November 2005, Stability Operations are now on equal ground with combat operations in the DoD mindset.

One of the key areas in Stability Operations that is lacking in research methodology is how to downsize the force once operations are underway. The United States European Command (EUCOM) has sponsored this research to explore new methods for commanders to determine when it is acceptable to downsize a force without sacrificing mission success or significantly increasing the force protection risk. This thesis develops a methodology for providing insight into such a problem by quantifying the conflicting objectives of force protection risk, mission failure risk, and time in the context of the operational threat environment.

Bosnia is a good example that demonstrated sensible force downsizing as the threat environment improved. As the situation improved, the force was able to continue to successfully redeploy, while accomplishing regional stabilization. If force levels were maintained at a constant level during an improving threat situation, there would have been identifiable points where the force became overkill. These identifiable points are referred to as the “trade-space,” where a smaller force can effectively accomplish the mission and continue progress toward a stabilized region, even if it takes more time.

To identify the trade-space, the Pythagoras Multi-Agent Simulation (MAS) and data farming techniques are used to investigate force-level comparisons in a theoretical threat continuum. Three scenarios of different sized forces are constructed based on the

U.S. peacekeeping mission in Bosnia from 1995 to 2004. A screen shot of the Division-sized force is seen in Figure ES1. Although the research is based on the Bosnian peacekeeping mission, the same methodology can be used to develop tools for identifying the trade-space in any Stability Operation in any region of the world.

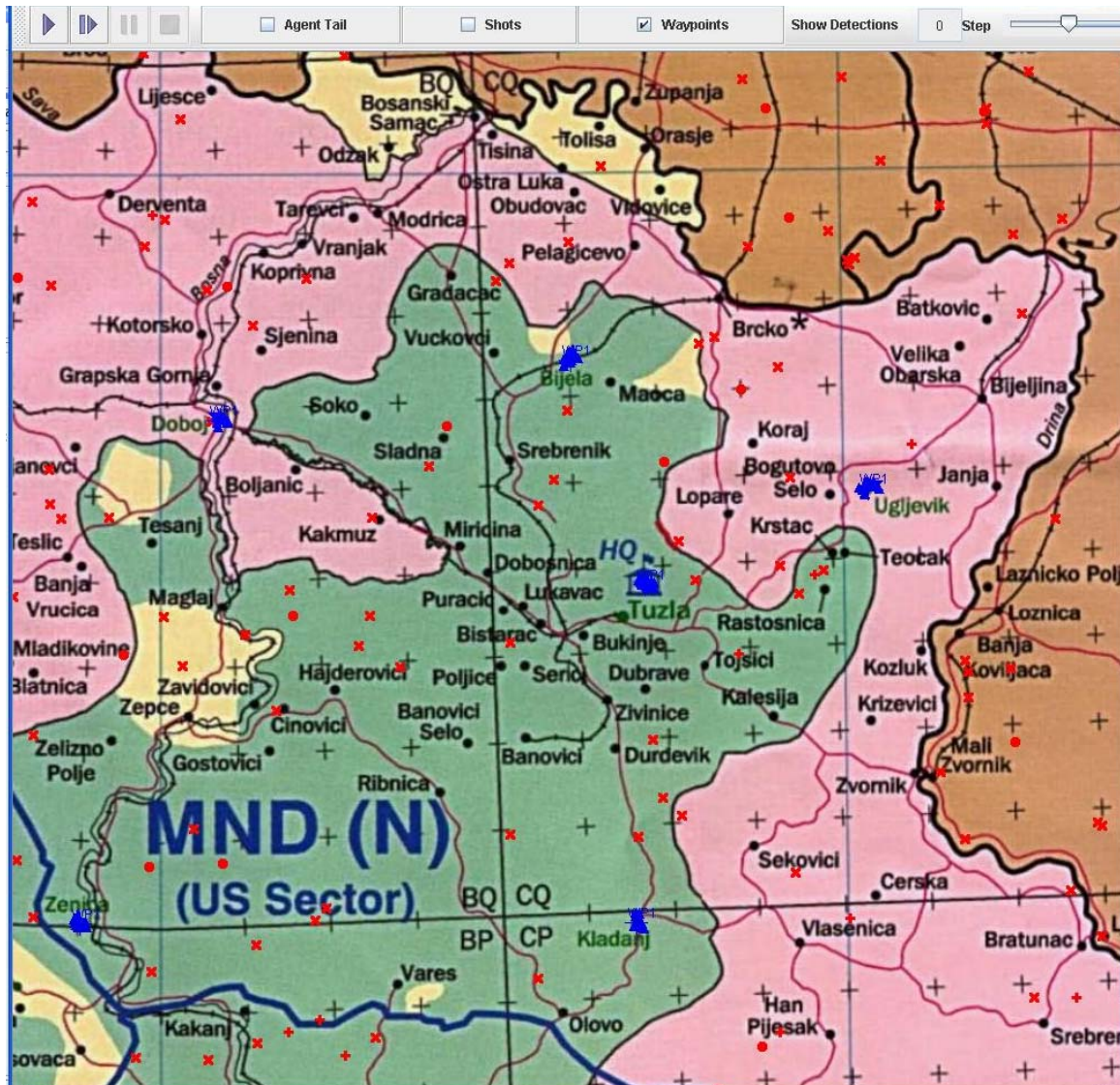


Figure ES1. Pythagoras Screen Shot of U.S. Sector, North East Bosnia (Division-Sized Force Scenario)

The data from the simulation is used to construct simple trade-space plots to be used as a tool for decision makers. These tools, and the methodology to produce them, are the primary results of the research. The trade-space tools are used in unison to find

the proper balance between conflicting measures, according to the commander's priorities. Used simultaneously, an analyst can hypothesize the consequences of a certain course of action. Quick assessments can be made on the right size of the force to minimize the risk of failing the mission and the risk to the force. For example, Figure ES2 can be used as a tool for analysts in identifying the trade-space of a smaller force achieving a relative level of mission success of a larger force. Trade-space is identified where two line plots intersect (or come close to one another). For example, at threat level 9, a Division force can achieve approximately 60% area coverage in a 4-day period. The Brigade (–) force achieves the same level of 60% area coverage in a 10-day period. This is an identifiable trade-space at threat level 9. The proportional ratio for this trade-space is 10/4 units of time. In other words, a decision to downsize assumes that it will take 2½ times longer to achieve parity in the desired level of area coverage. Besides time, the other consideration in trade-space is the force protection risk, which can also be analyzed using similar trade-space plots.

Although a comparison of basing strategies is not an intended goal of this research, it is apparent that it is the most significant factor in achieving presence in a Stability Operation. Therefore, an important conclusion to deduce is the significance of troop posture on force size transitions. This is evident by the surprising success achieved by the smallest force. It was able to project a greater presence by utilizing small units dispersed throughout the U.S. sector, much like the Combined Action Platoons in Vietnam. The lesson here is that presence matters, and the best way to achieve presence is through dispersion. The simulations demonstrate that dispersion can have a greater impact on the presence projection than the size of the force.

When downsizing a force, military planners must consider how to use a smaller force in a more dispersed manner in order to project the same presence as the larger force. Currently there are no analytical methods for doing this. This research proposes a method to quantify and compare different force size and postures and their effect on mission success. Following this methodology, two areas are identified as significant in achieving greater presence. They are troop posturing and troop employment. However, the increase in presence for a smaller force is typically at the cost of greater risk in force

protection. This is why simple trade-space tools are required to quantifiably balance the risk between the two competing objectives; force protection and mission success.

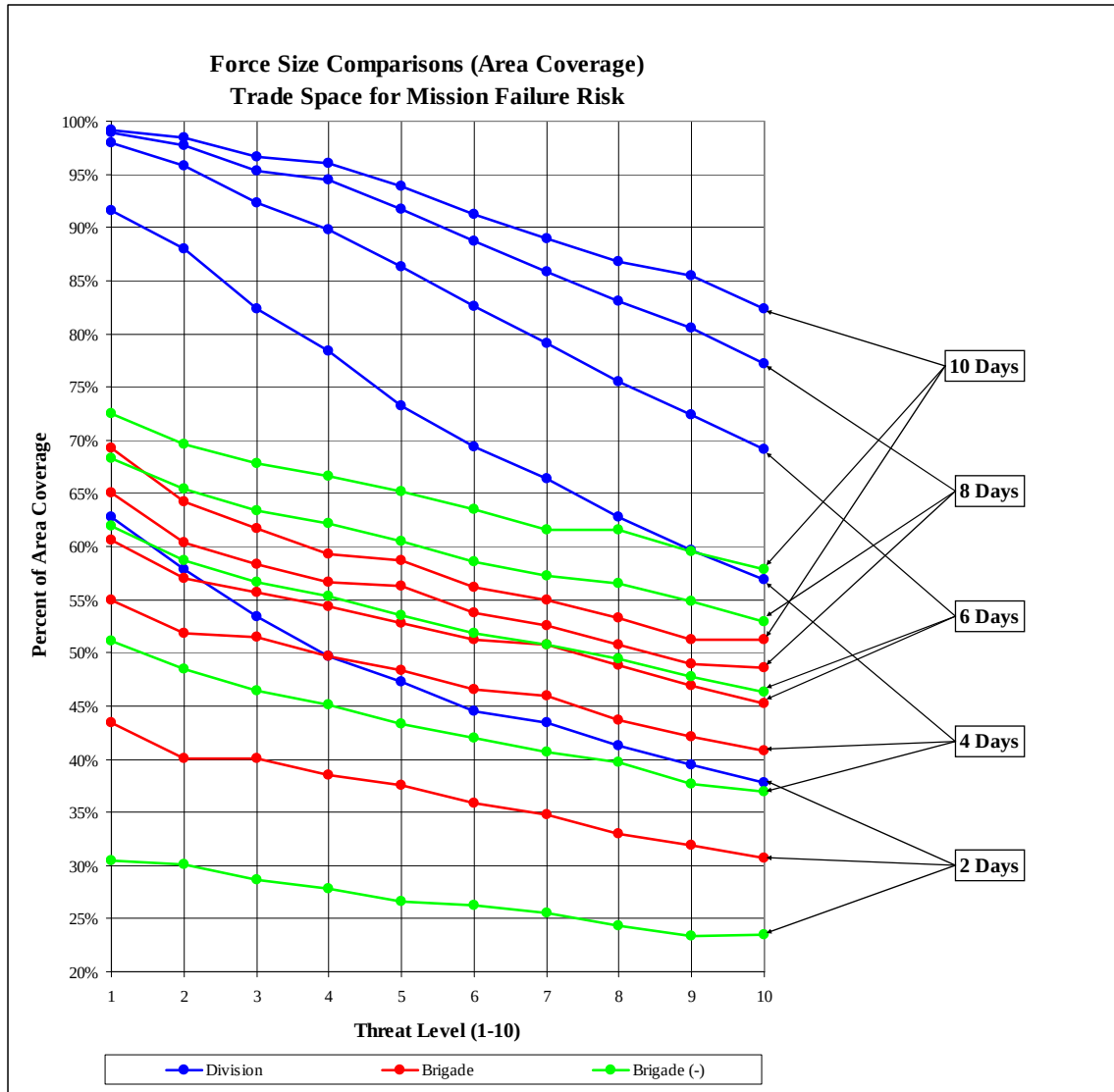


Figure ES2. Comparison of Area Coverage (Best viewed in color)

The first question always asked when considering a force downsizing is how big should the new force be? The problem is that the effects of troop posturing (basing strategies) and employment (patrol composition) are often overlooked or under emphasized. The results of this research demonstrate that posturing and employment

should be considered as factors equal to force size, in contributing to the goal of maximizing force presence. The tools presented here can aid in quantifying those contributions to a decision maker.

The significance of basing strategy is often lost by planners with the Cold War mentality of collapsing back on positions. The results from the simulations emphasize the importance basing or troop posture had on the ability of the force to project presence. This highlights the need for decision makers to maintain the focus of “presence” and how to maximize it when downsizing the force. It should be intuitive that achieving presence is the most crucial principal in a Stability Operation. If this were not the case, the force would not bother to deploy.

Even though troop posturing is often overlooked as a significant factor in achieving presence; troop employment is probably more so. Typically, force protection concerns dictate the employment of patrols (size and composition). This approach can result in unnecessarily large patrols that can be both intimidating and limit the number and frequency of patrols generated. Consideration should be given to the effect smaller patrols could have in influencing and building rapport with the population. Smaller patrols are certainly more approachable, with sympathetic locals willing to provide information of operational value. Smaller patrols also allow a force to generate more units to blanket the country side and achieve presence. The risks of operating smaller more autonomous patrols can be offset by a mobile and responsive Quick Reaction Force, either in the air and/or on the ground.

Besides providing insight into force transitions, the other goal of this research is to structure a thought process for considering the threat environment when evaluating when to downsize a force. There will always be the political and economic factors that can override all other considerations in downsizing a force. However, from a military decision maker’s standpoint, the first concerns are the risk of failing the mission followed by the force protection risk. These two concerns (objectives) are often conflicting. An increase in one objective usually means sacrificing in the other. The third dimension added to these two objectives is time. An increase or decrease in one of the risk objectives will inevitably effect the duration of the operation. As time increases, often so does risk.

Although analysts often use the phrase, “the model says this ...”, the truth is a model will never give a decision maker the answer. People make decisions, not models. However, models are often the foundation for developing the insight to make a good decision. The insights gleaned by the analyst using the model as a tool is the real value and insight given to the problem. This research provides a vehicle to assist military planners in looking at ways in which a stability force can maximize its presence and maintain it near continuously, while simultaneously minimizing the risk to the force and adhere to operational timelines. This is a difficult task due to the dynamic nature of Stability Operations. Therefore, this thesis presents a method to assist in simplifying the complex analysis required to make force reduction decisions.

I. INTRODUCTION

Peacekeeping is not a soldiers job, but only a soldier can do it.¹

Former UN Secretary-General Dag Hammarskjöld

A. OVERVIEW

Stability Operations have become the most prevalent mission for the deployment and employment of military forces in the current global security environment. Since the end of the Cold War, U.S. forces, within various international coalitions, have participated in more Stability and Support Operations (SASO) than major combat operations. Since 1990, the United Nations (UN) has sponsored 42 peace operations.² Including Iraq, Afghanistan, and other non-UN sanctioned operations, the United States has been involved in over 45 stability operations over the last decade and a half.

This shift in focus from combat to Stability Operations led to a significant Department of Defense (DoD) policy change, such “that stability operations are a core U.S. Military mission that the DoD shall be prepared to conduct and support. They shall be given priority comparable to combat operations and be explicitly addressed and integrated across all DoD activities.”³ This shift, giving Stability Operations training and equipping priority equal to combat operations, is significant for the current and future role of the U.S. military within the national security strategy. Therefore, the U.S. military is exploring innovative ways to plan for and execute Stability Operations.

It is important to state up front that many terms associated with the various types of Stability Operations are used interchangeably. This research will focus primarily on the peace operations category of Stability Operations. However, “stability operations are neither discrete nor mutually exclusive. For example, a force engaged in a peace operation may also find itself conducting arms control or a show of force to shape the

¹ Headquarters, Department of the Army, FM 100-23, *Peace Operations*, 30 December 1994, p. 1.

² United Nations Website, <http://www.un.org/Depts/dpko/dpko/timeline/pages/timeline.html>. Last accessed on 14 July 2006.

³ United States Department of Defense, Department of Defense Directive (DoDD) 3000.25, *Military Support for Stability, Security, Transition, and Reconstruction (SSTR) Operations*, 28 November 2005, p. 2.

conditions for achieving an end state.”⁴ Although the primary focus of this research is on peace operations, the term “Stability Operations” will primarily be used throughout to encompass the overlap of mission types. Figure 1 shows the ten sub categories of Stability Operations as well as the missions that make up the subcategories. For definitions of specific Stability Operations terms see Appendix A, Terms and Definitions.

TYPES OF MILITARY OPERATIONS	OFFENSE	DEFENSE	STABILITY	SUPPORT
TYPES OF STABILITY OPERATIONS AND THEIR SUBORDINATE FORMS	Peace Operations • Peacekeeping • Peace Enforcement • Operations in Support of Diplomatic Efforts Foreign Internal Defense • Indirect Support • Direct Support • Combat Operations Security Assistance Humanitarian and Civic Assistance Support to Insurgencies • Unconventional Warfare • Conventional Combat Actions Support to Counterdrug Operations • Detection and Monitoring • Host-Nation Support • C4 • Intelligence, Planning, CSS, Training, and Manpower Support • Reconnaissance		Combatting Terrorism • Antiterrorism • Counterterrorism Noncombatant Evacuation Operations Arms Control • Inspection • Protection • Destruction Show of Force • Increased Force Visibility • Exercises and Demonstrations	

Figure 1. Stability Operations⁵

The objective of peace operations is to establish the rule of law and an indigenous capability to maintain the peace so that the peacekeeping force (PKF) can redeploy. The sooner the mission is completed, the less risk the PKF is exposed to and the less costly the mission will be. However, the view that larger and more capable forces face diminished risks in deployment makes downsizing an unappealing option. Consequently, commanders of a PKF have traditionally desired to maintain the highest level of forces possible, thereby giving them the greatest capability. This is a prudent mindset for traditional combat operations; however, in peace operations there are transition points where a commander can downsize the force without detriment to the mission. If the conditions are acceptable to do so, a commander should downsize the force in a more

⁴ Headquarters, Department of the Army, FM 3-07, *Stability Operations and Support Operations*, February 2003, p. 1-4.

⁵ Ibid.

accelerated manner to reap the benefits of conservation of forces, cost savings, and limiting exposure to risk. This is assuming that downsizing would not excessively jeopardize mission accomplishment or exacerbate risk. However, it is likely that an aggressive downsizing would result in extending the mission duration.

United States European Command (EUCOM) has sponsored this research to explore new methods for commanders to determine when it is acceptable to downsize a PKF without sacrificing mission success or significantly increasing the force protection risk. Simply waiting until political decision makers impose force withdrawals is not an effective use of finite military personnel and resources. As such, DoDD 3000.05 directed the Under Secretary of Defense for Policy (USD(P)) to “create a stability operations center to coordinate stability operations research, education and training, and lessons-learned.”⁶ It is this center that will be the hub of all DoD Stability Operations research efforts, and a goal of this research is to contribute to this center’s body of knowledge.

The intent of this research effort is to provide a method for conducting a quantitative assessment of force downsizing in a Stability Operation. Chapter I provides a general overview of the topic at hand, which is identifying acceptable transition points for a commander in a stability operation to downsize his force. Acceptable refers to “mission failure risk” and “force protection risk.” The transition points will be described in the context of the operational threat environment. A Multi-Agent Simulation (MAS)⁷ is used to identify the transition points that allow a smaller force to accomplish the same mission as a larger force, although it might take more time. A force downsized prematurely risks failing the mission. This is referred to as “mission failure risk.” In addition, a force downsized prematurely could provide the enemy with an opportunity to regroup, thereby exposing the force to even greater risk. This is referred to as “force protection risk.” The following section covers the origins of this research effort.

⁶ United States Department of Defense, Department of Defense Directive (DoDD) 3000.25, *Military Support for Stability, Security, Transition, and Reconstruction (SSTR) Operations*, 28 November 2005, p. 5.

⁷ Multi-Agent Simulations (MAS) and Agent-Based Models (ABM) are used interchangeably. See Appendix A for definitions of both terms.

B. BACKGROUND AND MOTIVATION

Studying new approaches to Stability Operations is an important issue for the U.S. military. There are various methodologies proposed to study the unique problems that arise in such missions. This research proposes a unique approach using MAS. MAS and data farming techniques are relatively new in the operations analysis field. We will explore the stability operation's missions using insights from this approach. More importantly perhaps, we will evaluate the suitability of these tools for conducting analysis of Stability Operations.

DoDD 3000.05 directs the Combatant Commands to "designate an appropriate military officer as the Joint Force Coordinating Authority for Stability Operations."⁸ This individual is charged with submitting "stability operations ideas and issues to Commander, U.S. Joint Forces Command (USJFCOM), for further exploration as part of the joint experimentation program."⁹ The Commander, USJFCOM is then directed, in coordination with the USD(P) to "explore new stability operations concepts and capabilities as part of the joint concept development and experimentation program." Furthermore, USJFCOM will "establish, design, and conduct experiments to identify innovative ideas for Stability Operations, in coordination with Combatant Commanders." In compliance with this directive, EUCOM is taking a proactive approach to explore new ideas in planning for and analyzing Stability Operations.

EUCOM chose to lead and support this research because it is relevant to their theater of operations. The EUCOM area of responsibility (AOR) covers 92 countries, 46 million square miles, and 28% of the earth's oceans. The AOR includes all of Europe, Russia, Israel, and the African continent.¹⁰ Since the fall of the Soviet Union, EUCOM is no longer focused on the Soviet threat nor are there any major conflicts threatening Europe. EUCOM's main focus is on preventing the conditions that lead to failing states and regions that result in conflict. If conflict does occur, it is likely EUCOM will engage

⁸ United States Department of Defense, Department of Defense Directive (DoDD) 3000.25, *Military Support for Stability, Security, Transition, and Reconstruction (SSTR) Operations*, 28 November 2005, p. 9.

⁹ Ibid., p. 9.

¹⁰ Kenya, Somalia, Ethiopia, Eritrea, Djibouti, Sudan and Egypt are the exception. These countries are part of Central Command.

in Stability Operations, “to promote and protect U.S. national interests.”¹¹ Due to the nature of recent conflicts in the Balkans and the African continent, EUCOM will probably continue to engage in Stability Operations and therefore must continue to explore ways of conducting them successfully.

EUCOM just completed a nine-year peacekeeping mission in Bosnia-Herzegovina as part of the NATO-led PKF and continues to conduct Stability Operations in Kosovo as well as provide troops for Afghanistan and Iraq. EUCOM has compiled many lessons learned from past stability operations such as the Bosnia and Kosovo campaigns. Using these lessons, efforts aimed at improving the analysis involved in planning and executing these types of operations will continue.

EUCOM’s Plans Division (J5-P) and Operations Research and Analysis Division (J8-R) sponsored this research to explore areas that support planning for Stability Operations. The J5/J8’s search for tools that will aid in the analysis of planning and executing Stability Operations is ongoing. The redeployment issue is a critical decision and the “how” and “when” to downsize the PKF is part of the exit strategy that is laid down at the beginning of operations. Currently, there is no doctrine or structured framework for such decisions. It is obvious that every operation will be unique and there can be no catch-all policy for a force downsizing decision. There are simply too many factors to consider in these complex operations. However, efforts can be made to take an analytical approach to downsizing a force. Such an approach, as this research shows, can assist a decision maker in helping to frame his thought process, identify issues that must be taken into consideration, and assess the logical consequences of various assumptions.

C. RESEARCH PROBLEM STATEMENT (QUESTIONS)

There are so many issues to consider in a force downsizing decision that they cannot all be examined in this research. Therefore, this study only looks at the threat environment, which is arguably the most important aspect of the decision. What follows is a short description of what this research addresses.

When first assigned a stability operation mission, the commander must take sufficient forces to handle all of the potential threats that might be poised against him. His first missions are to show the appropriate level of force, separate the warring factions,

¹¹ Headquarters, Department of the Army, FM 3-07, *Stability Operations and Support Operations*, February 2003, p. 1-4.

and start providing a safe and secure environment for other actions to take place. At the beginning stages, a commander must be given an overwhelming force to ensure that a safe and secure environment can be established as quickly as possible. Otherwise, he risks the rise of an insurgency, as seen in Iraq. Once the first stages of providing a safe and secure environment have been achieved, and the threat environment improves, forces can be considered for withdrawal. The focus of this research is to identify where such “trigger points” or “trade-space” exist. First, identify where in a threat continuum a commander can drawdown his forces without putting them in more danger (force protection risk). Second, identify where in a threat continuum a commander can drawdown his forces without risking a reversal of a safe and secure environment (mission failure risk). The purpose of this study is to identify the “trade-space” within a threat continuum, in order to assist a commander in making prudent drawdown decisions.

Downsizing the force is in the best interest of the ongoing peacekeeping/peace enforcement mission and the overall U.S. national defense interests, because it allows those forces to be utilized for future mission requirements. In addition, it reduces the overall force operational tempo.

Our three primary assumptions are, first, a commander is given an “overwhelming force” to ensure that a safe and secure environment can be achieved as quickly as possible. Second, once the beginning stages of a safe and secure environment are achieved, drawdown considerations can and should be made. Basically, this assumption is saying, forces can be redeployed without taking imprudent risks in force protection or mission accomplishment. Third, this research assumes that the threat continuum in the real world can be measured to an acceptable level of accuracy.

Measuring or estimating the threat environment is not a trivial thing to do. In all operations, forces measure and estimate the threat environment. In the planning process, planners are required to measure the risk and provide an estimate of the threat environment for the commander. In many cases, the measurements are subjective and specific to that particular operation. Knowing that the definitions and metrics of a threat environment are highly subjective and can be very complex, this paper simplifies both.

In this study, the threat continuum is limited to threats normally confronted in peacekeeping/peace enforcement operations. Typically, these include threats up to a low-intensity conflict, but stop short of threats in the mid-intensity conflict range. How the threat continuum is defined and measured in the research is discussed in more detail in Chapter III, Section C.

D. BENEFITS OF THE STUDY

A stability operation is complex.

To trace every one of its effects in detail would be a fantastically complicated task. However, as Aesop discovered some time ago, the details of reality can disguise essential truths that are best revealed through simple fictions. If we can't understand highly stylized artificial examples, we have no hope of understanding the world.¹²

This research aims to strip away some of the complexities that can obscure a decision and look at Stability Operations in a relatively simplistic form using an MAS. Using a modeling approach, this research isolates the concern of force protection risk and mission failure risk as a PKF is downsized. Utilizing simple modeling and simulation (M&S) techniques has proven to be an effective way to isolate areas of concern associated with certain decisions. However, models don't make decisions, people make decisions. Therefore, the overarching benefit of this study is a proposed methodology, utilizing simple models, to assist in framing a decision-making process. Current events demonstrate that troop downsizing will be an important decision facing commanders in the near future.

U.S. commanders in Iraq and Afghanistan will eventually be faced with troop downsizing. These decisions will ultimately rest in the hands of civilian leadership, but the responsibility of the military leadership is to advise them on what the risks are related to force downsizing. Structuring a thought process can assist military commanders in advising the decision maker. As previously stated, the default judgment for most commanders is to maintain the greatest capability possible, while minimizing the risk to the force. This mindset must be changed in order to free up forces for other operations. Commanders must make timely recommendations on when it is feasible to downsize a

¹² Steven Landsburg, *The Armchair Economist*, The Free Press (Simon & Shuster), 1995, pp. 34, 51, and 56.

force and what that force composition should be. If sound methods are developed that can assist a commander in evaluating a prudent time to downsize a force, they will be more inclined to make such recommendations.

Bosnia is a good example that demonstrated sensible force downsizing as the threat environment improved. As the situation and threat environment improved, the force was able to continue to successfully redeploy, while accomplishing regional stabilization. If force levels were maintained at a constant level during an improving threat situation, there would have been identifiable points where the PKF became overkill. This identifiable point can be considered the “trade-space,” where a smaller force can effectively accomplish the mission and continue progress toward a stabilized region.

For EUCOM, the benefit of the research is to define and document where a commander can prudently drawdown the size of his force and free those forces for other contingency missions. The main purpose of a military force in a peacekeeping/enforcement role is to provide a safe and secure environment so other agencies can come in and help the nation rebuild. The following section will give a brief overview of the methodology used to identify the “trade-space.”

E. METHODOLOGY

This study hypothesizes 10 levels of threat within a peacekeeping/peace enforcement continuum. A level 10 threat requires more forces and more effort than a level 9 threat, and so on. Therefore, this research models three different force levels against the entire threat continuum to identify where (in the simulation) a commander could reduce the force without a significant increase in risk to force protection or mission failure. It is at these threat levels where we believe there is an identifiable “trade space” or region where a smaller force can assume the mission from a larger force. It is possible a force to be downsized without increasing those two areas of risk, but it will likely take the smaller force more time to accomplish the same mission as the larger force. That is what is meant by identifying “trade-space”—it is trading capability and speed in order to achieve a reduction in the overall size of the force.

To identify the “trade-space,” an MAS and data farming techniques are used to investigate force-level comparisons in a threat continuum. Three scenarios are created in

the Pythagoras MAS. The scenarios are loosely constructed around the U.S. peacekeeping mission in Bosnia. The United States was a major contributor to the NATO Stabilization Force (SFOR) in Bosnia since its beginning in December 1995 to its termination in December 2004. During those nine years, SFOR went through many transformations as the mission of the PKF changed. The first scenario models U.S. forces at their highest level, which was approximately a division or 10,000 troops. The second scenario models when U.S. forces downsized to a brigade, or roughly 5,000 troops. The last scenario models the final years of SFOR when the U.S. contingent was reduced to three battalions, or roughly 2,000 troops.

Each scenario evaluates the force against the full spectrum of threats encountered in peacekeeping/peace enforcement operations. Comparisons are then made in both mission failure risk and force protection risk across all three scenarios. Conclusions are drawn on regions in the threat continuum where a smaller force can achieve similar levels of success as the larger force. These regions are referred to as the “trade-space” or “transition-points.”

For simplicity, the threat continuum is thought of on a theoretical scale of 1 to 10, with level 10 being the most severe. Each level of the scale can be thought to contain events that are representative of real-world missions in Stability Operations.¹³ Levels 1 through 5 of the threat continuum are considered the peacekeeping missions, whereas levels 6 through 10 fall into the peace enforcement missions. It is in the peace enforcement arena where units are more likely to face threats such as improvised explosive devices (IEDs), minefields, suicide bombers, ambushes, mortar attacks, or snipers.

Events, as they are called in the model, represent incidents that U.S. forces respond to. They range from conducting “get acquainted” meetings with local leaders, all the way up to a full-scale insurgency, in which reacting to IEDs and ambushes are commonplace. It is not important in terms of the simulation to define what real-world events comprise a particular “event” level. Doing so would raise the question of relative severity between specific events. It is too subjective to determine how much influence or presence it takes to quell a riot compared to how much presence it takes to shake hands

¹³ For examples of the simulation “events,” see Appendix B.

with a mayor. The abstract scale of 1 to 10 is an aggregate of all the types of events that could occur in a peacekeeping/peace enforcement mission. The important concept to consider is the varying degrees of events that occur and a scale representative of all of them.

The following chapter goes into greater detail on the methodology used in the development of the model. It covers the specifics of the scenarios and their implementation in the Pythagoras model. In addition, Chapter II expands on how the threat continuum is defined and measured within the simulation.

Once the construction of the model is defined, Chapter III describes the design of experiment (DOE) used in running the simulation. It reviews the parameters of the simulation explored in the design and how these parameters were selected.

The data output from the simulation is reviewed in Chapter IV. Using statistical techniques, conclusions are drawn on how the “transition points” or “trade-space” are identified within the operational threat environment.

Chapter V summarizes the data analysis done in the previous chapter to provide the findings of the research. Inevitably, there are always unanswered questions. Therefore, Chapter VI concludes with recommendations, as well as areas for further study. At the conclusion of this paper the reader should have an understanding of the research methodology used to recreate scenarios with alternative assumptions. Ultimately, the take-away for the reader should be the conclusions on identifying “trade-space” within a threat environment. A residual benefit is the thought process from which to evaluate the threat environment in a Stability Operations setting.

II. MODEL DEVELOPMENT

A. INTRODUCTION

This chapter discusses the approach used to build the model using the Pythagoras MAS. The model scenario was developed based on U.S. peacekeeping efforts in Bosnia from 1995-2004. The overall intent is to develop three scenarios that capture a macro view of U.S. forces in a stability operation. Each of the three scenarios employs a different size blue¹⁴ force against a full, theoretical, threat spectrum. Each force size is then compared, based on its success against the threat continuum. The comparisons are made from outputs from the simulation, measuring degrees of mission failure risk and force protection risk.

B. MULTI-AGENT SIMULATIONS (MAS)

The terms Multi-Agent Simulations (MAS) and Agent-Based Models (ABM) are used interchangeably in the Modeling and Simulation (M&S) community and can be defined in many different ways. To put it simply, a MAS is

. . . a simulation made up of agents, objects or entities that behave autonomously. These agents are aware of (and interact with) their local environment through simple internal rules for decision-making, movement, and action. The aggregate behavior of the simulated system is the result of the dense interaction of the relatively simple behaviors of the individual simulated agents.¹⁵

The key word in this definition is “simple.” If the rule sets for agent behavior become too complex, the agent behavior can become erratic and difficult for the analyst to explain. Likewise, if scenarios become too complex, the analyst loses the ability to know what is occurring within the model. If the analyst loses the ability to understand agent behavior, then he is missing the strength of MAS, which lies in the analyst’s ability to observe agents’ emergent behavior and then understand why it occurred.

The basic premise of MAS is to assign rule sets that govern individual agent’s behavior to sense their environment and then shoot, move, and communicate

¹⁴ Throughout the paper “agents” (entities within the simulation) are referred to simply as “red” or “blue” agents. This follows the common convention of referring to friendly forces as “blue forces” and opposing forces (OPFOR) or enemy forces as “red forces.”

¹⁵ Susan Sanchez and Thomas Lucas, “Exploring the World of Agent-Based Simulations: Simple Models, Complex Analyses,” Proceedings of the 2002 Winter Simulation Conference.

accordingly.¹⁶ The simplicity of MAS then allows the analyst to conduct data farming. Data farming is conducted by running the model multiple times, simultaneously varying parameters to gain insight into complex interactions. It is the complex interactions of agent parameters that develop agent “emergent behavior.” Just like real world complex adaptive systems, multi-agent simulations can simulate behaviors that are not captured or observed in traditional combat simulations.

C. THE PYTHAGORAS MODEL

Of the available MAS in the M&S community, Pythagoras was chosen because it offers the greatest flexibility in its features and functions. All MAS have their strengths and weaknesses. However, Pythagoras’ strength for modeling abstract concepts, such as influence projection and the value of presence in Stability Operations made it the obvious choice. The German MAS PAX,¹⁷ is structured specifically for investigating the intangibles of peace operations; however, PAX is geographically constrained to micro terrain of roughly a city block. For this reason, the Pythagoras MAS is used for this research instead of PAX.

It would be contradictory to say Pythagoras is a one-size-fits-all model, since no such model exists. However, utilizing a little creativity, an analyst can model almost any concept using Pythagoras. The catch is that the concept must remain relatively simple. As previously discussed, if the concept is overly complex, low resolution MAS are not the right tool for the analysis. Nevertheless, complex scenarios, such as Stability Operations, can be modeled using MAS when broken down into small, aggregated vignettes. An analyst using Pythagoras will gain the most insight with the proper balance of simplicity and detail. The level of detail should be just enough to adequately model

¹⁶ The Defense Modeling and Simulation Office (DMSO) uses the term *Intelligent Agent* and defines it as: “A software entity that carries out a set of operations on behalf of a user with some degree of independence or autonomy, and in so doing, employs knowledge or representation of the user’s goals or desires.” Susan M. Sanchez and Thomas W. Lucas, “Exploring the World of Agent-Based Simulations: Simple Models, Complex Analyses,” Proceedings of the 2002 Winter Simulation Conference, <http://www.informs-cs.org/wsc02papers/015.pdf?search=%22exploring%20the%20world%20of%20Agent-Based%20simulations%22>. Last accessed on 28 August 2006.

¹⁷ PAX was developed by the European Aeronautic Defence and Space (EADS) Company. PAX has been used in the Project Albert collaborative community applying MAS to military problems. The Bundeswehr (German Armed Forces) has used PAX to study various aspects of peace operations. The PAX model is named after the goddess of peace in Roman mythology and is also the Latin word for peace. DMSO Online Glossary, https://www.dmsol.org/public/resources/glossary/results?do=get&search_text=agent. Last accessed on 28 August 2006.

the question at hand. In many cases, analysts default to “more is better” in terms of the amount of detail. It is widely thought that the more details you can capture in your model the better representation it will be of the real world. This is not necessarily the case with MAS, and it is why MAS are often referred to as distillations.

1. Pythagoras Developmental History

In 1998, the Marine Corps Combat Development Command (MCCDC) and the Marine Corps Warfighting Lab (MCWL) received congressional funding to initiate a new program called Project Albert. “Project Albert is a modeling and simulation initiative that combines the rapid prototyping of agent-based distillations with the exploratory power of data farming to rapidly generate insight into military questions. Data farming focuses on the complete landscape of possible system responses, rather than attempting to pinpoint an answer.”¹⁸

MCWL contracted with Northrop Grumman to build a MAS based on the capabilities of ISAAC, EINStein, and Archimedes.¹⁹ Northrop Grumman took a ground up approach in developing Pythagoras to meet the requirements of MCWL. The requirements were relatively simple: build a MAS that “Uses Fuzzy Logic, can run both batch on a computer cluster and from a Graphical Users Interface (GUI) on a personal computer (PC), and is easy enough that a Marine history major can use it.”²⁰

By April 2002, Northrop Grumman delivered the initial version, Pythagoras (v1.0). As the model was used and tested at the Warfighting Lab, additional capabilities and requirements were identified and bugs in the code were fixed. As a result, Northrop Grumman released an updated version of the model about every six months, adding new features and correcting the bugs. The current version, v1.10, released in May 2006, has significant capabilities and improvements over the initial version that came out in 2002.

¹⁸ Proceedings of the 2005 Winter Simulation Conference, “MARINE CORPS APPLICATIONS OF DATA FARMING”, Adam J. Forsyth, Gary E. Horne, and Stephen C. Upton, <http://www.informs-cs.org/wsc05papers/129.pdf#search=%22MARINE%20CORPS%20APPLICATIONS%20OF%20DATA%20%22>, p. 1077. Last accessed on 28 August 2006.

¹⁹ ISAAC, EINStein, and Archimedes are early versions of MAS. Irreducible Semi-Autonomous Adaptive Combat (ISAAC) and Enhanced Isaac Neural Simulation Toolkit (EINStein) were developed by the Center for Naval Analyses (CNA). <http://www.cna.org/isaac/>. Last accessed on 28 August 2006.

²⁰ Edmund Bitinas, Zoe Henscheid, and Donna Middleton, *Pythagoras User’s Manual*, v1.10, May 2006, Northrop Grumman Mission Systems, pp. 22-23.

2. Model Overview (Characteristics of Pythagoras)

One of the uses of MAS is to capture the intangibles of warfare that often are not studied in an analytical way. Through the use of MAS and data farming, analysts have been able to gain insight into military questions that normally are studied in an analytical fashion.²¹

Like most models that are termed “agent-based,” in Pythagoras you build your scenario and observe the emergent behavior of the agents. More specifically, you define the terrain, the weapons, the sensors, the communications, the agents, and the agent’s desires. From these given characteristics, the agents sense their environment and make decisions to shoot, move, and communicate based on their desires. Pythagoras has the flexibility to be completely random in nature or perfectly scripted. The benefit of MAS is the randomness that is representative of the real world. Pythagoras allows an analyst to investigate how randomness affects the outcome of an agent’s behavior and the outcome of the modeled scenario.

Within Pythagoras, agents view other agents by their color combination of red, green, blue (RGB). This is referred to as sidedness. Agents classify other agents in one or more of four categories: Unit, Friend, Neutral, or Enemy. The sidedness allows the user the flexibility of changing how agents see their world and how they are seen by other agents. For example, at the start of a simulation, a blue force might not be able to distinguish insurgents²² from civilians, but through the actions of the insurgent his “sidedness” could change and the blue force would now be able to distinguish insurgents from civilians.

Pythagoras is a time-step model, so the user defines the real world equivalent of one time-step.²³ This is important because time (duration of one time-step) and space (distance of one pixel) affects the speed and movement of the agents in the model, as well as the performance of weapons, sensors, and communications.

²¹ Many examples of studies using MAS can be found in *Maneuver Warfare Science 2001-2003*, Horne and Johnson. These are annual USMC/Project Albert publications of research conducted using MAS and data farming.

²² **Insurgent:** Member of a political party who rebels against established leadership. JP 1-02, DOD Dictionary of Military and Associated Terms, 12 April 2001, as amended through 14 April 2006, <http://www.dtic.mil/doctrine/jel/doddict/>. Last accessed on 28 August 2006.

²³ One time-step in the scenarios in this thesis is defined as 2½ minutes of real-world time.

Once the scenario has been created, the simulation is easy to run many times in batch on a single PC or a cluster of computers. By varying the parameters, data analysis can be done to determine significant factors affecting the outcome of the model.

To create a scenario the user first builds the terrain and agents using Pythagoras's GUI. Agents must be assigned weapons and sensors that allow them to sense their environment and interact with other agents. Communications may also be assigned as another means for agents to interact and exchange information. Developing terrain will be discussed first, followed by agent development.

Terrain — Terrain size is defined as a rectangular grid measured in pixels. The size of the grid (number of pixels) is the area agents have to move within the scenario. The maximum allowed terrain size (play box) is 1,000 pixels x 1,000 pixels. Within the play box, any type of terrain feature can be added that can provide an agent cover and concealment and limit its mobility, just like real-world terrain features.

Agents — An agent's design is the most important piece of MAS, and therefore is the most complex piece to construct. There are a number of possible parameters that define an agent within Pythagoras, however, it is not required to use (define) every parameter for each individual agent.²⁴ Agents are typically thought of as people, vehicles, or equipment capable of sensing and responding within the simulation. Agents can be abstract ideas, such as escalation in a threat environment or events (incidents) occurring within the operational environment. Both of these abstract concepts are used in the scenarios in this research and will be discussed in detail.

A detailed description of terrain and agent development in Pythagoras can be found in Appendix B.

3. Model Capabilities and Limitations

Pythagoras has many strengths and the greatest is its flexibility. Its applications are only limited by the user's imagination. Agents are not restricted to represent physical entities in the real world (people, vehicles, equipment, etc.). Anything that can influence the outcome can be modeled to some level in Pythagoras. The parameters in Pythagoras are set up and described like most combat-oriented simulations. However, military

²⁴ For a complete list of agent parameters, see the *Pythagoras User's Manual*.

parameters, like weapons, can be used for abstract ideas like influence weapons or “paintball” weapons that inflict color change on agents, and therefore change how agents view one another (sidedness).

Pythagoras has the ability to model abstract ideas through the use of colors and generic parameters like attributes and resources. Much like the use of colors, generic attributes and resources can be defined as anything. For example, a generic attribute can be used as a measure of fear and a generic resource can be used as a measure of rations. The generic attributes and resources can be used to affect how an agent views its environment and how it reacts. Agents then make decisions based on their own levels of color, attributes, or resources. Agents can also make decisions based on other agent’s levels of color, attributes, or resources.

The generic parameters, and nearly all other parameters, in Pythagoras are considered data farmable, which means that the parameters can be varied according to an experimental design. This allows the user to conduct sensitivity analysis on the parameters in the model. This is critical to finding parameters that the model’s outcomes are sensitive to and therefore require further analysis.

Besides its flexibility, another strength of Pythagoras is its relative simplicity. A user can be trained on how to use the software in just a few hours. From there, in a matter of days, scenarios can be constructed, run on a PC, and results analyzed. However, like most software packages, a user must invest significantly more than just a few days to truly become proficient with its features.

Since Pythagoras is written in the Java programming language, it is combatable with virtually any computer. In addition, it is widely available to analysts in the DoD M&S community as well as international partners affiliated with Project Albert. This compatibility and availability allows anyone to use and learn from the model. Analysts learning the software have had the assistance of the Northrop Grumman developers, who have been very responsive to user problems and concerns. When possible, they have added capabilities at an individual’s request. This level of support should continue as long as possible.

Despite all its strengths, Pythagoras, as with all models, does have some weaknesses. Many of the weaknesses can be attributed to the fact that Pythagoras is a

work in progress. The developers have been able to make improvements and add capability rather quickly by releasing updated beta versions to its users. Therefore, it is often the users who find bugs in the code or features of the model that do not work properly. This can be frustrating to an analyst developing a scenario; however, it is the trade-off for the fast development of the program. A new user of Pythagoras might not be adept at recognizing a bug and assume the model is functioning correctly. This could result in an analyst using bad data produced by a scenario that is not functioning properly. This can only be prevented by carefully examining all parameter inputs and observing the simulation with the play-forward tool. Then, after initial data are received, the analyst can conduct some preliminary analysis to determine if the results are “in the ballpark” of what was expected. If not, the results could be a consequence of errors within the model.

Pythagoras is a low-resolution model, and therefore scenarios are kept relatively simple.²⁵ This can be problematic because most military scenarios are anything but simple. One of the challenges for the user is to take a very complex environment and distill it down to fundamental parts that can be studied and analyzed. Although the low fidelity of this model is viewed by some as a weakness, Pythagoras can provide insight into parameter settings for higher fidelity models that takes much longer to build, script, and run.

MAS are not usually formally Validated, Verified, and Accredited models (VV&A). This makes some in the M&S community skeptical and untrusting of the data, and therefore any analysis done with the data is dismissed. This is more of a cultural consideration of the M&S community as a whole, rather than a specific weakness of Pythagoras.

Pythagoras has a limited number of agent behaviors and behavior change triggers; however, with some creativity it is possible to find ways to build a particular behavior for an agent using color and generic attribute/resource combinations. The risk of this is that behavior is inevitably affected by subjective input from the modeler.

²⁵ A simple scenario refers to using a small number of agents operating within a small geographical terrain box over a short time duration. There are no limits on these three criteria; however, the larger they get, the slower Pythagoras runs, and the more likely it is for the simulation to fail. For example, during long simulation durations, converting shorts to longs and back to shorts resulted in agent terrain coordinates being calculated as outside the terrain box.

Terrain is very limited in Pythagoras and there is no three-dimensional movement. Complex terrain can result in erratic agent behavior due to the Pythagoras movement algorithms. In particular, agents “hop” a certain number of pixels each move, rather than move through those pixels. This can result in agents “hopping” into terrain or obstacles that are meant to restrict an agent’s movement (i.e., a wall). Once in this terrain, an agent can become stuck for the remainder of the simulation.

The initial effort in this research developed complex road networks representative of the roads in Bosnia. This posed a problem for agents to negotiate turns in the roads, due to the movement algorithms and had to be abandoned. Although this is a departure from the actual terrain in Bosnia, the spatial separations between towns and villages are maintained.

Another limitation of terrain is that it is limited to 1,000 pixels x 1,000 pixels. The scale of the terrain has implications in all aspects of the model including weapon range, sensor range, communications range, movement rates, etc. With the large geographical scale of this scenario (130 km x 130 km) each pixel represents 130 meters x 130 meters. This does not allow adequate fidelity to model real world weapons systems. In addition, all agent movements are based on a defined pixel per time-step rate. When a pixel represents long distances, it restricts how the analyst can define a time-step. This is because if either pixel distance or time-step duration becomes too large, then the number of pixels an agent moves (actually hops) per time-step can grow. If the movement of pixels per time-step is too large, erratic behavior can result. For example, agents can “hop” into terrain that is designed to be 100% restrictive, such as a wall. Once in this terrain they become stuck and can not move. Through model development, it was determined that a movement rate above 15 pixels per time-step results in erratic movement behavior. Results will differ depending on the terrain; however, a good rule of thumb is that the higher the movement rate of an agent, the greater the chances of impracticable behaviors occurring.

The only way to confirm a modeled scenario is running properly is to watch a visual representation in the GUI, which Pythagoras calls the play-forward tool. After visual verification, the model can be run many times to generate data, which can provide further insight into potential problems with the model construct. Any unusual data can

point to problems that can be played back with the unique seed in the play-forward tool. This process of visual and data verification can refine scenarios, but it does not catch everything. In the model development process, many scenarios were run with problems in the code that were unknown at the time. These problems were not recognized visually in the GUI or in the data results. This “black box” symptom can result in bad data and be unknown to the analyst.

It is assumed that features operate as advertised with a model, but this is not always the case and there is no good way to verify this. For example, restorative weapons at one point were having the effect of degrading agent’s health rather than restoring it. In addition, agents were shooting through obstacles (such as walls) that were meant to provide 100% protection. These are examples of problems that can be very difficult to catch if there is a problem in the code.

As Pythagoras is used more, the bugs will be identified and corrected. Eventually, the concern over Pythagoras’s features working properly will subside and analysts will only have to worry about agent behaviors that result from the parameter inputs, not errors in the code.

D. SCENARIO DESCRIPTION

1. Situation

As previously discussed, all scenarios modeled for this research are based on the Bosnian peacekeeping mission. This provides a baseline from which to start; however, the specifics of the Bosnian campaign are not crucial to the simulation. It simply helped to frame the geographical size of an operation, force structure, opposition forces, and missions of the PKF. The same methodology used to develop the scenarios on Bosnia can be used for any region of the world.

U.S. forces deployed to Bosnia as part of the UN-sanctioned SFOR. For the mission, Bosnia was divided into thirds—with the U.S. responsible for the northern sector of the country. Eagle Base, in Tuzla, was established as the headquarters of the U.S. sector. Tuzla is roughly centered within the U.S. sector and can be identified by the arrow in Figure 2.



Figure 2. SFOR Multinational Division (MND) Boundaries²⁶

2. Scenario General Situation

In the first scenario, U.S. forces deploy a division-sized force of roughly 10,000 troops. Approximately half of those forces are based at Eagle Base in Tuzla. The other 5,000 troops are equally distributed among five smaller outlying camps at Doboj, Bijela, Ugičevik, Kladanj, and Zenica (shown in green in Figure 3). Each outlying camp is assigned an Area of Responsibility (AOR) for day-to-day operations of patrolling and peacekeeping. However, units mutually support adjacent units outside of their immediate AOR.

²⁶ Map downloaded from http://www.lib.utexas.edu/maps/bosnia/bosnia_sfor_97.jpg, Last accessed on September 20, 2006.

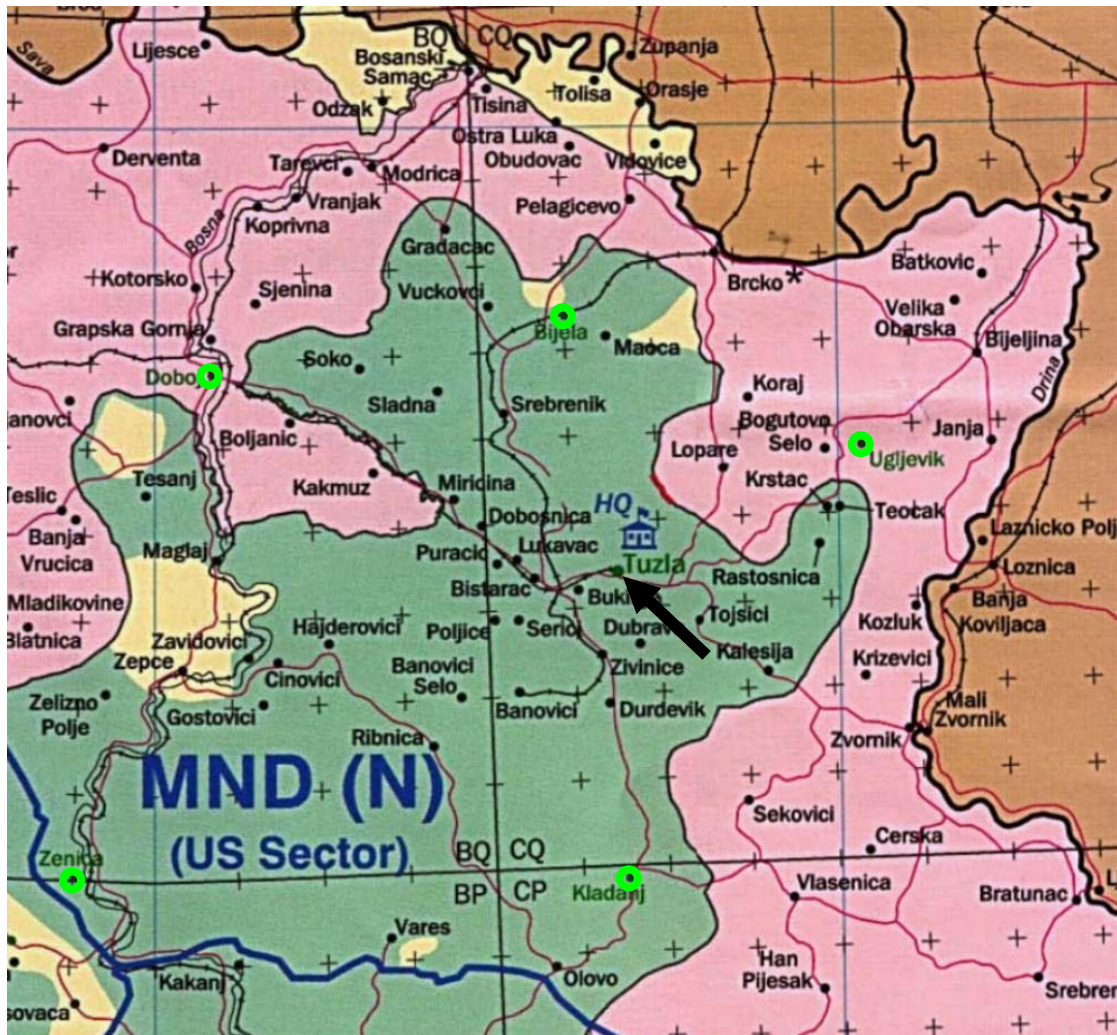


Figure 3. U.S. Sector, Northeast Bosnia (Best viewed in color)²⁷

As the threat environment diminishes, and the region moves closer to stability, the force is downsized to a Brigade of roughly 5,000 troops. This is the composition for scenario two. The smaller sized force does not require the same number of bases and therefore three are closed. Approximately 3,000 troops remain at Eagle Base and 1,000 troops remain at Camp Bijela (in the north) and 1,000 troops remain at Camp Kladanj (in the south). Fewer troops and camps result in each unit's AORs expanding in order to cover the entire U.S. sector. This also results in greater travel times for patrols covering their AOR.

²⁷ Map downloaded from http://www.lib.utexas.edu/maps/bosnia/bosnia_sfor_97.jpg, Last accessed on September 20, 2006.

As the region continued to move toward stability, U.S. forces downsized to a Brigade (-), roughly three battalions or 2,000 troops. This is the composition for scenario three. With three battalions it is infeasible to maintain the logistical requirements of Eagle Base and two outlying camps. Therefore, the outlying camps are closed and Eagle Base remains as the only U.S. military camp. When this downsizing occurred in the real world Bosnia operation it presented the problem of distances (travel times) for patrols leaving from Eagle Base. Due to poor mobility over rough terrain, it would take over three hours each way for a patrol to reach outlying towns within the sector. This only allowed a few hours of troop presence once a patrol reached its assigned area. This was impractical, so planners looked at alternatives to continue the mission with the remaining forces. The solution was to lease private buildings (base-houses²⁸) from which to operate. This allowed a squad to maintain a 24/7 presence in the outlying areas and eliminate the long transit times from Eagle Base. Small-sized units, typically a squad, would rotate out to the base-house for a week or two at a time to conduct patrolling missions. These small units were essentially self-sufficient, living off the local economy. This approach assumed greater risk in force protection, but mitigated the risk of deteriorating stability by the lack of a continual presence (mission failure risk). The third scenario modeled simulates the dispersion of the base-house concept used in Bosnia.

²⁸ In Bosnia, toward the end of U.S. participation in SFOR, troops were living in leased houses and buildings in areas far from Eagle Base in Tuzla. These buildings were often referred to as a “safe house.” Joint Pub 1-02 defines a safe house as, “an innocent-appearing house or premises established by an organization for the purpose of conducting clandestine or covert activity in relative security.” The use of these houses, in the context of this study, was not for covert or clandestine activity. They were used for a base of operations, therefore the term “base house” will be used in this paper to better describe the concept. JP 1-02, DoD Dictionary of Military and Associated Terms, 12 April 2001, as amended through 14 April 2006, <http://www.dtic.mil/doctrine/jel/doddict/>. Last accessed on 28 August 2006.

3. Special Situation

The operational environment of all three scenarios is considered to be permissive to uncertain.²⁹ The defining characteristic of the threat continuum in the simulated operational environment is the distribution of various events.

To develop a threat continuum, we hypothesized 10 levels of threats with each threat level comprised of 10 levels of “events.” A level 1 event might be an angry mayor. The force level required to neutralize this event is defined in the model as low. The force protection risk is also defined as low. At the high end of the scale, a level 10 event might be an insurgent-led ambush against a patrol. The force level required to neutralize this event is defined in the model as high and the force protection risk is also defined as high. Each event level is defined based on how easily it can be influenced (vulnerability) or how easily it can influence blue forces (marksmanship). A level 10 event is not easily influenced and can exert a great deal of negative influence against blue forces. A level 1 event is easily influenced and exerts a very low amount of influence against blue forces.

Each threat level is comprised of 100 individual events of varying levels of severity. A threat level 1 consists of mainly lower level events with only a few higher-level events imposed against the force. A threat level 10 consists of more higher-level events and fewer lower-level events against a force. The distributions of events are discussed in detail in Chapter III.

In the simulation, U.S. forces patrol regions in their assigned AOR based on the threats (insurgents and events) perceived by their sensors, rather than set patrol routes. In reality patrols have a definite route, destination, and mission prior to setting out on a

²⁹ **Operational Environment** – A composite of the conditions, circumstances, and influences that affect the employment of military forces and bear on the decisions of the unit commander. Some examples are:

Permissive Environment: Operational environment in which host country military and law enforcement agencies have control as well as the intent and capability to assist operations that a unit intends to conduct.

Uncertain Environment: Operational environment in which host government forces, whether opposed to or receptive to operations that a unit intends to conduct, do not have total effective control of the territory and population in the intended operational area.

Hostile Environment: Operational environment in which hostile forces have control as well as the intent and capability to effectively oppose or react to the operations a unit intends to conduct.

JP 1-02, DOD Dictionary of Military and Associated Terms, 12 April 2001, as amended through 14 April 2006, <http://www.dtic.mil/doctrine/jel/doddict/>. Last accessed on 28 August 2006.

patrol. Within the simulation the patrol mission concept is abstracted. Patrols move to events that they have knowledge of through their own sensors or information from other units. This maintains the stochastic behavior of agents based on their rule sets, rather than trying to “script” their behavior by mandating hard waypoints to follow. When a patrol becomes active in the simulation, it moves toward events or insurgents it senses, rather than following a fixed set of waypoints. This gives each patrol a varying route, destination, and mission each time it sets out on patrol, rather than repeating the same actions each time. This is realistic in that variations in patrol routing are crucial to force protection by avoiding predictability.

Figure 3, shows the actual 1,000 pixels x 1000 pixels (130 km x 130 km) terrain map used in the Pythagoras simulation. Although it doesn’t completely cover the U.S. sector, it is deemed adequate in representing the distances patrols are required to travel to reach assigned mission areas. In all three scenarios, a pixel is defined as 130 meters x 130 meters (approximately 0.0065 square miles or 4.2 acres) and 1 time-step equals 2½ minutes. These two definitions affect all aspects of time and space in the model, including agent movement, sensors, and weapons. For more detail on time and spatial breakdowns within the model see Appendix B.

Since agents are allowed to move generally throughout the terrain or “play box,” agents are allowed to move into a small portion of the French sector to the south and the British sector to the west, which can be seen in Figure 2. Although in the real world this would not occur without prior coordination, it is reasonable to give blue agents the same freedom of movement as red agents.

4. Enemy Force

Enemy forces consist of hostile³⁰ actors referred to as insurgents within the model. The insurgent’s intent is to disrupt the SFOR forces from accomplishing their mission. They do not have the capability to take on blue forces in a decisive engagement, however, they will utilize hit-and-run tactics to disrupt and delay blue’s mission. Each enemy agent class will be discussed below in the simulation agents section.

³⁰ **Hostile:** In combat and combat support operations, an identity applied to a track declared to belong to any opposing nation, party, group, or entity, which by virtue of its behavior or information collected on it such as characteristics, origin, or nationality contributes to the threat to friendly forces. JP 1-02, DoD Dictionary of Military and Associated Terms, 12 April 2001, as amended through 14 April 2006, <http://www.dtic.mil/doctrine/jel/doddict/>. Last accessed on 28 August 2006.

5. Friendly Forces

Three scenarios are constructed in Pythagoras using the three different force sizes and structures. Each force size and its derivation for the model are discussed in detail in Section E.

6. Mission

The mission of U.S. forces operating under NATO is to maintain the peace in accordance with the Dayton Peace Accord and to “help ensure compliance with the provisions of this agreement.”³¹

7. Execution

Blue patrols strive to positively influence as many events as they can during their patrol duration. Forces are divided into 12-hour cycles (day and night patrols) with approximately two-thirds of the force patrolling during daylight hours and one-third patrolling during nighttime hours.

Patrolling is a key factor in most PKOs. If it is well planned and executed, patrolling can achieve important tactical advantages for the peacekeeper. To be effective, patrolling parties need freedom of movement and observation. Patrols have a combination of four tasks: information gathering, investigating, supervising, and publicizing a presence. The mere presence of a peacekeeping patrolling unit, or the likelihood that one may appear at any moment, deters potential breakers of an armistice agreement. The presence of peacekeeping troops in a tense situation has a reassuring and calming effect in troubled areas.³²

8. Administration and Logistics

All logistics and enabling forces have been stripped from the simulation. The contribution of these forces is accounted for in increased situational awareness and force protection in garrison for larger-sized forces. Since the logistics of Stability Operations is not a concern for this study, they are not included to any level of detail from which conclusions can be drawn.

³¹ Dayton Peace Accords, Annex 1A: Agreement on the Military Aspects of the Peace Settlement, Article I, General Obligations 1(a), <http://www.yale.edu/lawweb/avalon/intdip/bosnia/day02.htm>. Last accessed on 28 August 2006.

³² Headquarters, Department of the Army, FM 7-98, *Operations in a Low-Intensity Conflict*, Chapter 4, Peacekeeping, Section 4-12, Patrolling, Washington, D.C.: 19 October 1992, http://www.globalsecurity.org/military/library/policy/army/fm/7-98/F798_5.htm. Last accessed on 28 August 2006.

9. Command and Signal

a. Command

There is no established hierarchy of command for either red or blue forces. For this scenario, it is deemed to be an insignificant dynamic for the behavior of patrols. Since each agent represents an aggregate of forces there is insufficient fidelity to require levels of leadership and command hierarchy. All blue patrols are viewed the same by red agents. Likewise, all insurgent agents are viewed as equal threats to blue patrols. Command and control of forces is not one of the aspects of this research and therefore is not included in the simulation.

b. Signal

Each patrol maintains contact with other patrols in its unit as well as adjacent units through a feature in Pythagoras that allows an agent to “always know about unit” and “always know about friends.” This can be thought of as perfect communications. Everyone can agree that most operations do not have perfect communications, particularly in rough terrain like Bosnia; however, investigating the effects of degraded communications is not a goal of this research. Therefore, all scenarios have roughly the same communications capability as discussed below under sensor description.

E. BLUE FORCE COMPOSITION

This section breaks down the formulation of the numbers of agents used in each scenario. It further discusses how those numbers were derived and assumptions made.

Each scenario consists of a different size force. The largest scenario consists of a division-sized force of 10,000 troops. The scenario is then modified to simulate a downsized force of a brigade. This scenario consists of a Stryker Brigade of 5,000 troops. The final scenario is a further downsizing to a brigade (–)-sized force (three battalions) of roughly 2,000 troops. Each scenario is discussed individually to explain the rationale for the numbers used within the simulation.

FM 7-98 states, “Brigade-size units and below conduct most U.S. peacekeeping operations. The basic force structure and augmentation are situation-dependent.”³³

³³ Headquarters, Department of the Army, FM 7-98, *Operations in a Low-Intensity Conflict*, Chapter 4, Peacekeeping, Section II, Missions of a Peacekeeping Force, Washington, D.C.: 19 October 1992, http://www.globalsecurity.org/military/library/policy/army/fm/7-98/F798_5.htm. Last accessed on 28 August 2006.

However, it is likely that larger operations will require a force larger than a brigade. In addition, it is unlikely that the mission will end with the brigade conducting the mission. There is likely to be a requirement to maintain forces smaller than a brigade for a sustained period as the region is stabilized and handed over to the host nation's security forces.

The same study could have been conducted starting with a brigade, and looked at the trade space when transitioning down to a company-sized force. However, it is likely that a company-sized force would strictly be in an observer/advisor role and not conducting patrolling operations, as did the brigade-sized force. The three blue force structures used in this research all conduct similar operations, only on different scales.

1. Scenario 1 (Division-Sized Force)

Within the graphical display of the simulation, each agent type has a different shape icon. The different icons are depicted in Figure 4. The starting lay down of agents within in scenario one are depicted in Figure 5. All red agents are randomly distributed at run start. All blue agents start at their assigned base.

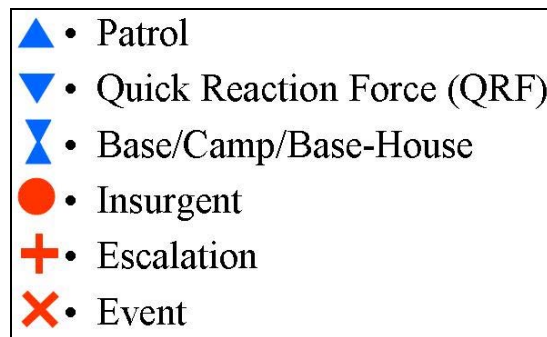


Figure 4. Agent Icons within the Pythagoras Model

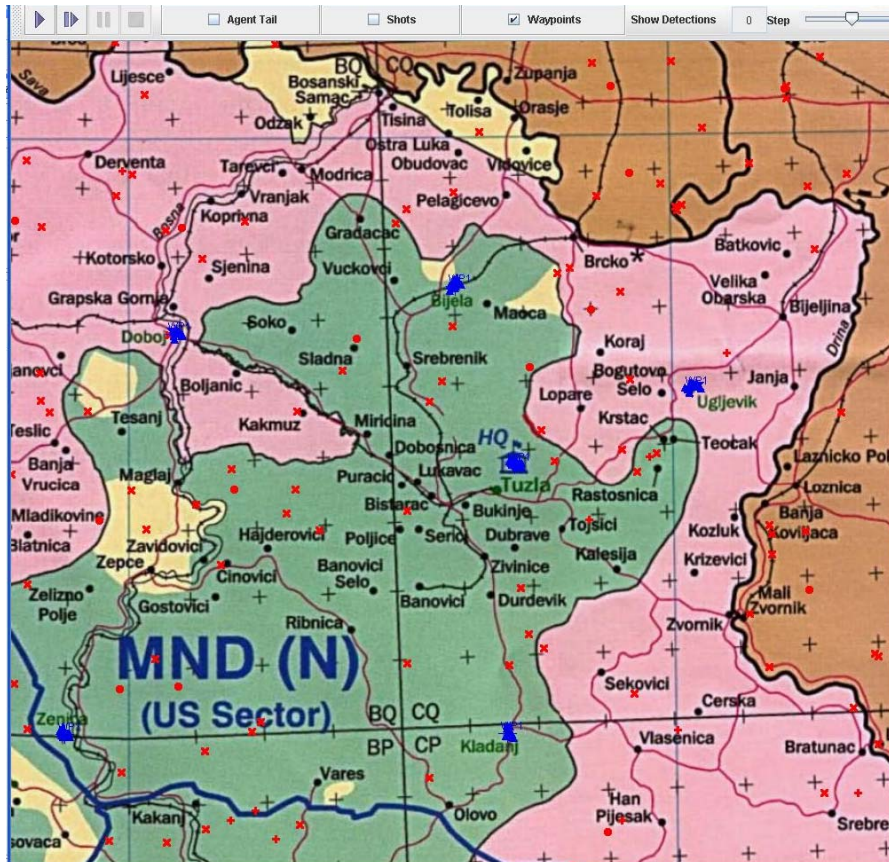


Figure 5. Pythagoras Screen Shot of Division-Sized Force Scenario (Best viewed in color)

2. Organization

The division force deploys from one main operating base (Eagle Base) and five satellite camps. The division is composed of a Stryker Brigade and a mechanized heavy brigade. The mechanized heavy brigade consists of 2 battalions of mechanized forces (M2A2 Bradley infantry fighting vehicle (IFV)), 1 armored battalion (M1A1 Abrams main battle tank), 1 artillery battalion, and 1 engineer battalion. Unit organization tables were used as a reference to develop numbers of troops. FM 3-21.31 states, “The SBCT has an approximate personnel strength of 3,500 soldiers.”³⁴ However, 3,850 soldiers are used as an estimate for a Stryker Brigade. It is felt that an additional 350 troops are needed to include attached enabling forces. The mechanized heavy brigade estimate of troops available is 5,000. This number was estimated by the number of weapon systems

³⁴ Headquarters, Department of the Army, FM 3-21.31, The Stryker Brigade Combat Team, 13 March 2003, Chapter 1, Section 1-17, <http://www.globalsecurity.org/military/library/policy/army/fm/3-21-31/index.html>. Last accessed on 28 August 2006.

contained in the table of equipment for 2 mechanized battalions and 1 armored battalion. The number of systems was multiplied times the crew for each type of equipment. The actual size of any brigade will vary depending on the mission.

Table 1 breaks down the force structure and generation of aggregated patrol agents within the simulation.³⁵

Elements of the Division Force	# Troops
Division HQ	150
Mech Hvy Bde	5,000
Stryker Brigade	3,850
Enabling Force	1,000
Total Force	10,000
Patrol Capability	# Troops
1 x Armor Battalion (M1A1)	180
2 x Mech Battalion (M2A2 Bradley)	700
3 x Stryker Battalion(-) = 3 x 133	400
2 x Artillery Battalion	600
2 x Engineer Battalion	500
Base Security	-400
Reserve	-171
Crew Rest	-300
Troops available for patrolling	1,509
Capability (3-man element) (1509/3)	503

Table 1. Patrol Capability for Division Scenario

³⁵ Headquarters, Department of the Army, FM 3-21.31, *The Armored and Mechanized Infantry Brigade*, 8 January 1996, Chapter 1, Section II, Organizations and Functions, <http://www.globalsecurity.org/military/library/policy/army/fm/71-3/index.html>. Last accessed on 28 August 2006.

3. Equipment

The division-sized force includes a much larger complement of equipment than what is necessary to consider for this study. Only Stryker vehicles, M2A2 Bradley IFVs, and High Mobility Multi-Wheeled Vehicles (HMMWVs) are considered as main equipment used within the simulation. M1A1 main battle tanks and other major equipment are considered to be held in reserve at Eagle Base, but do not operate on day-to-day patrols.

4. Concept of Employment

A patrol in this scenario is defined as 9 soldiers, 2 armored HMMWVs, and 1 Stryker (or Bradley IFV)—as depicted in Figure 6. With a possible 503 three-man elements, it is possible to generate 168 patrols. Each patrol “agent” is an aggregate of 2 patrols. Therefore, the agent breakdown is as follows:

168	Patrols (Aggregated, One Agent = Two Patrols)
84	Patrol Agents
24	Agents @ Main Operating Base (MOB) (16 Day, 8 Night)
60	Agents @ Camps (12 per Camp), (8 Day, 4 Night)
21	Agents created, each with an instance of 4

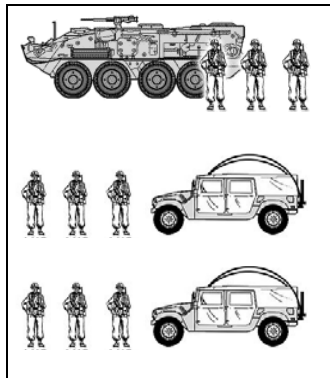


Figure 6. Division Scenario Patrol

The Quick Reaction Force (QRF) is composed of 6 soldiers and 2 Stryker vehicles, as depicted in Figure 7. The QRF is the same for all three scenarios. The only difference is the number of QRFs available. There are 6 QRFs in the Division Scenario, 1 at Eagle Base, and 1 each at the 5 satellite camps. The QRFs stand ready to respond to

calls for assistance from patrols. In the Brigade Scenario, there are 3 QRFs, 1 at Eagle Base and 1 each at the 2 satellite camps. In the Brigade (–) Scenario, there is only 1 QRF available at Eagle Base to cover the entire U.S. sector.

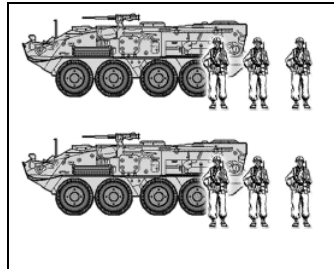


Figure 7. QRF Composition for All Three Scenarios

5. Scenario 2 (Brigade-Sized Force)

Figure 8 depicts the starting lay down of agents within the Brigade Scenario.

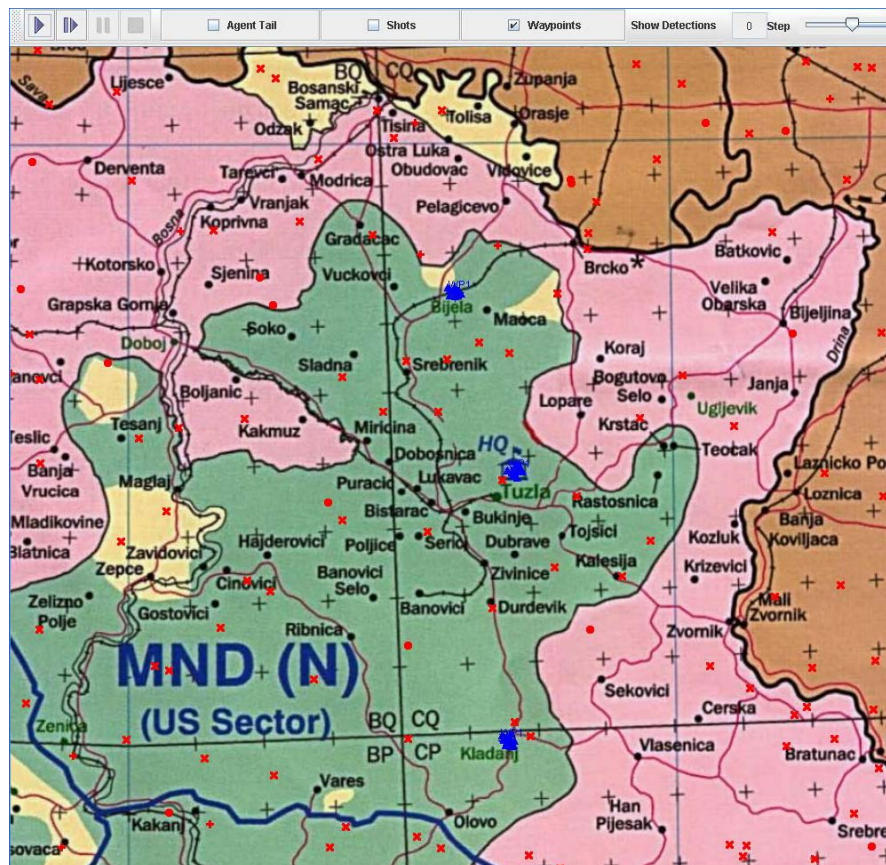


Figure 8. Pythagoras Screen Shot of Brigade-Size Force Scenario (Best viewed in color)

6. Organization

The number of patrols generated for the Brigade Scenario is based on the organization of a Stryker Brigade Combat Team (SBCT) (see Figure 9). Again, 3,850 is the troop strength estimate for a Stryker Brigade. The Brigade Headquarters (HQ) staff is half of the Division HQ staff. Likewise, the enabling force was halved from the Division Scenario. A dismounted infantry or light infantry battalion of 525 soldiers is added to supplement the soldiers of the Stryker Brigade.

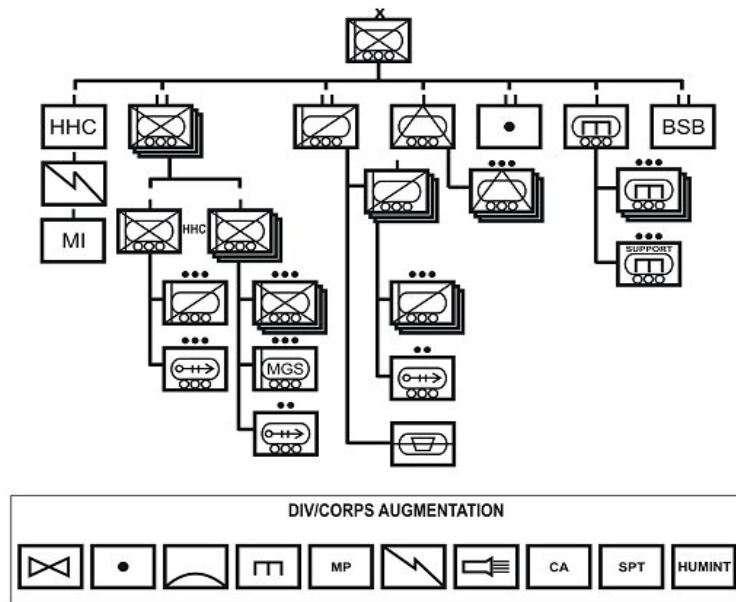


Figure 9. Stryker Brigade Combat Team³⁶

Table 2 breaks down the force structure and generation of aggregated patrol agents within the simulation.

³⁶ Headquarters, Department of the Army, FM 3-21.31, *The Stryker Brigade Combat Team*, 13 March 2003, Chapter 1, Section 1-17, <http://www.globalsecurity.org/military/library/policy/army/fm/3-21-31/index.html>. Last accessed on 28 August 2006.

Elements of the Brigade Force	# Troops
Brigade Headquarters (BDE HQ)	125
Stryker Brigade	3,850
Infantry Battalion	525
Enabling Force	500
Total Force	5,000
Patrol Capability	# Troops
3 x Stryker Battalion(-) = 3 x 133	400
1 x Infantry Battalion	350
1 x Artillery Battalion	300
1 x Engineer Battalion	250
Base Security	-140
Reserve	-174
Crew Rest	-230
Troops available for patrolling	756
Capability (3-man element)(756/3)	252

Table 2. Patrol Capability for Brigade Scenario

7. Equipment

Like the Division Scenario, only Stryker vehicles, M2A2 Bradley IFVs, and HMMWVs are considered as main equipment used within the simulation. All other equipment is considered part of the reserve force at Eagle Base.

8. Concept of Employment

A patrol in this scenario is defined as 6 soldiers and 2 armored HMMWVs, as depicted in Figure 10. With a possible 252 three-man elements, it is possible to generate 126 patrols. Again, each patrol agent in the simulation is an aggregate of 2 patrols. Therefore, the agent breakdown is as follows:

126	Patrols (Aggregated, One Agent = Two Patrols)
63	Patrol Agents
23	Agents @ Main Operating Base (MOB) (16 Day, 7 Night)
40	Agents @ Camps (20 per Camp), (12 Day, 8 Night)
15	Agents created, each with an instance of 4
1	Agent created with an instance of 3

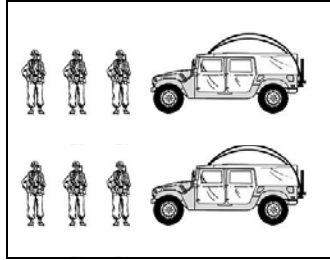


Figure 10. Brigade Scenario Patrol

9. Scenario 3 (Brigade (-)-Sized Force)

Figure 11 depicts the starting lay down of agents within the scenario.

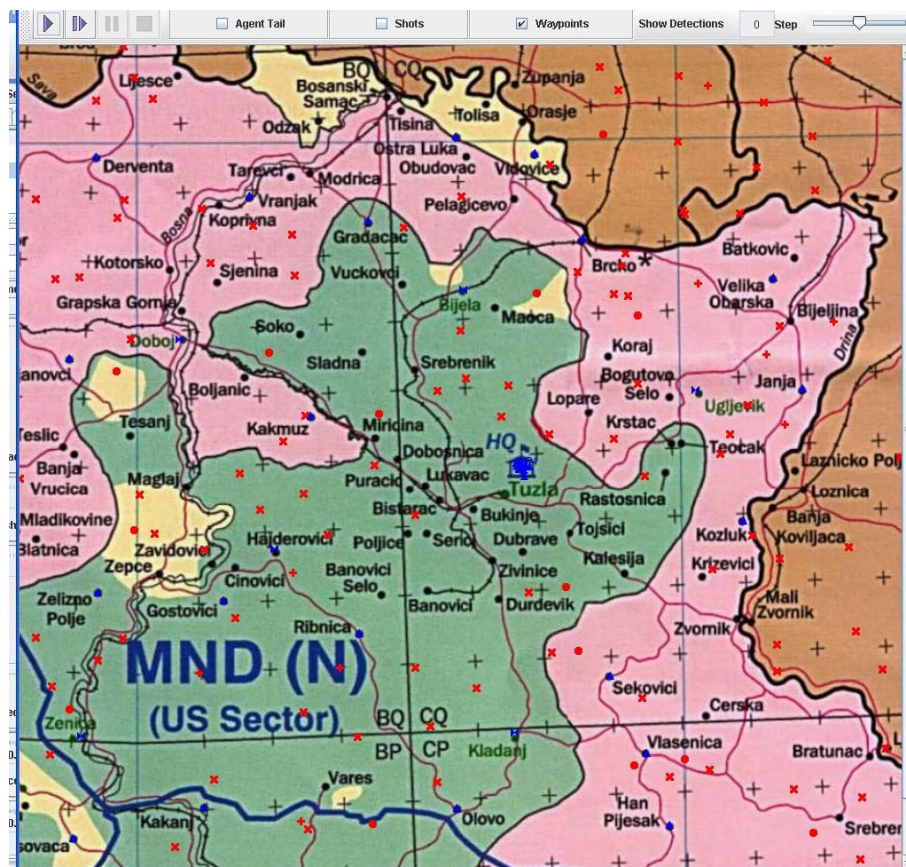


Figure 11. Pythagoras Screen Shot of Brigade (-)-Sized Force Scenario (Best viewed in color)

10. Organization

The number of patrols generated for the Brigade (–) Scenario is based on the organization of three Stryker Battalions, as depicted in Figure 12.³⁷ One battalion is based out of Eagle Base, one battalion is assigned responsibility for the northern half of the U.S. sector, and one battalion the southern half of the U.S. sector. The Battalion HQ for the northern sector is Bijela. The Bn HQ for the southern sector is Kladanj. The battalion in the northern AOR is subdivided into Company AORs, with Company HQs at Dobož, Bijela, and Ugijevik. The battalion in the southern AOR is subdivided into Company AORs with Company HQs at Zenica, Hajderovici, and Kladanj. The companies further subdivide into three or four base houses within their AOR from which to operate, as seen in Figure 11.

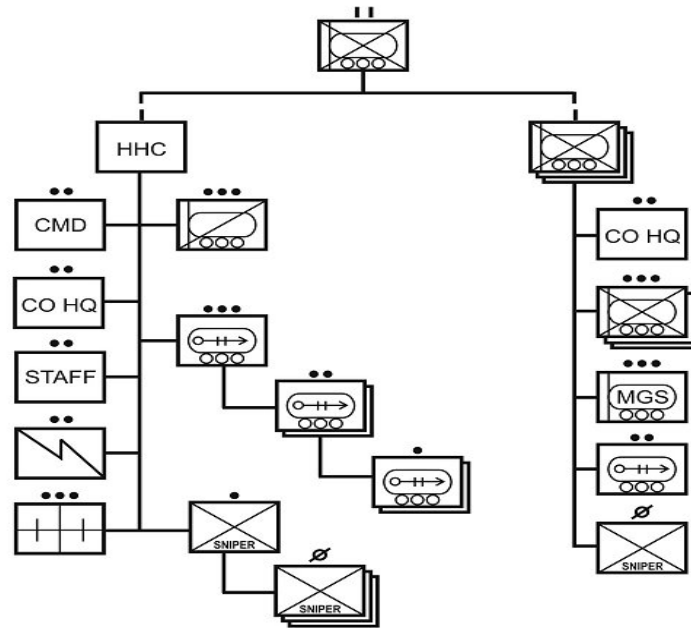


Figure 12. Stryker Battalion Organization³⁸

The following table breaks down the force structure and generation of aggregated patrol agents within the simulation.

³⁷ Headquarters, Department of the Army, FM 3-21.31, *The Stryker Brigade Combat Team*, 13 March 2003, Chapter 1, Section 1-17, <http://www.globalsecurity.org/military/library/policy/army/fm/3-21-31/index.html>. Last accessed on 28 August 2006.

³⁸ Headquarters, Department of the Army, FM 3-21.21, *The Stryker Brigade Combat Team Infantry Battalion*, April 2003, <http://www.globalsecurity.org/military/library/policy/army/fm/3-21-21/index.html>, p. 1-6. Last accessed on 28 August 2006.

Elements of the Brigade (-) Force	# Troops
Brigade Headquarters (BDE HQ)	75
3 x Stryker Battalion (-)	1,500
Consolidated Support (From Stryker Battalions)	255
Enabling Force	170
Total Force	2,000
Patrol Capability	# Troops
3 x Stryker Battalion = 3 x 133	398
Reserve/Crew Rest (MOB)	-146
Troops available for patrolling	252
Capability (3-man element) (252/3)	84

Table 3. Patrol Capability for Brigade (-) Scenario

11. Equipment

Within the simulation, only Stryker vehicles and HMMWVs are considered as main equipment. All other equipment is considered part of the reserve force at Eagle Base.

12. Concept of Employment

A patrol in this scenario is defined as 3 soldiers and 1 armored HMMWV, as depicted in Figure 13. Each of the 84 three-man elements is a patrol. Each patrol agent in the simulation is an aggregate of 2 patrols. Therefore, the agent breakdown is:

84 Patrols (Aggregated, One Agent = Two Patrols)

42 Patrol Agents

14 Agents @ Main Operating Base (MOB) (10 Day, 4 Night)

28 Agents @ Base Houses

10 = 2 Agents with an instance of 5 (Day) MOB

4 = 1 Agent with an instance of 4 (Night) MOB

6 = 6 Agents with an instance of 1 (Company HQ Safe House)

22 = 22 Agents with an instance of 1 (Platoon Safe House)

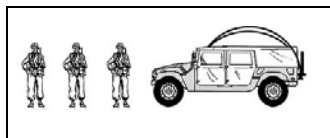


Figure 13. Brigade (-) Scenario Patrol

F. RED FORCE COMPOSITION

Although there were conventional forces engaged with one another in the Bosnian conflict, SFOR troops generally were not the target of their rounds. Serbian forces realized that if they challenged NATO conventionally, forces would be brought to bear that would destroy them. Therefore, the opposition typically faced was small bands of insurgent-type cells. Within the simulation, “insurgent” agents represent the same types of cells whose intent is to disrupt U.S. operations. Other red forces in the simulation include, “Event” agents, and “Escalation” agents. Descriptions of these agents are discussed in Section G.1.

G. CHARACTERISTICS OF THE SIMULATION

In the conceptual model, each scenario was constructed with METT-TSL³⁹ as a basis for decisions that departed from actual events in Bosnia. Each scenario is run for a simulated period of 2, 4, 6, 8, and 10 days. This is considered a long duration for MAS; however, the extended time is necessary to capture the cause and effect of troop presence (or lack thereof). For example, if a demonstration takes place, it could quickly escalate to a violent situation or riot if a PKF does not respond in a timely manner. Through the use of escalation agents in the model, events can become more intense without a persistent PKF presence.

Patrols operate on two shifts for roughly an eight-hour patrol, as depicted in Figure 14. Each day duration in the simulation is somewhat accelerated. Realistically, the “events” that patrols respond to in the simulation would occur over several months, not several days. The operational tempo (op tempo) was condensed to test each force and evaluate its performance under stressful conditions. Each scenario is pitted against the same accelerated situation; therefore, the increased op tempo has no bearing on the outcome.

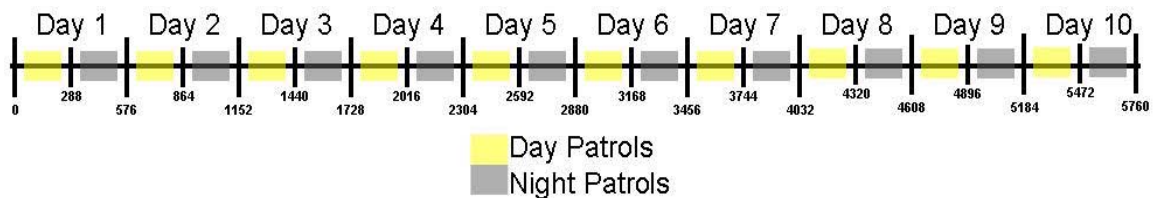


Figure 14. Simulation Duration (in Time-Steps)

³⁹ Acronym used in military mission planning to consider the key areas of Mission, Enemy, Terrain/Weather, Troops/Fire Support available, Time, Space, Logistics.

1. Agents

All agents start with a “health” of 1.0; however, health is used as a conceptual measure of an agent’s overall well-being.⁴⁰ It is best thought of as an agent’s strength and determination to continue its mission. As an agent’s health is degraded, its desires and actions change.

All agents have thresholds within their health levels that alter their behavior. This is discussed individually below for each agent type. Agents whose health is depleted to 0.0 are considered dead within the simulation, however, the location of dead agents can be retained in other agent memories for resurrection. This concept is discussed more under the Escalation agent in Section e.

a. *Blue Force Agents: Base Agents, Camp Agents, and Base-House Agents*

These agents simulate the force protection provided by the different-sized garrisons. The larger the base, the more troops and fortifications are in place, and therefore, the better the force protection. Troops in a base house are more vulnerable than troops in a camp, who are more vulnerable than troops at Eagle Base.

The base, camp, and base-house agents all have lethal “influence” weapons simulating the actual base security providing troops force protection. These agents also have “restorative” weapons that restore patrol agents “health” upon returning to base. This is a conceptual way of simulating a patrol resting and reequipping before setting out on another patrol. The key parameter values of these agents are listed in Table 4.⁴¹

	Base Agent	Camp Agent	Base-House Agent
Weapon Range (pixels)	50	25	10
Weapon Effectiveness	0.5	0.5	0.5
Marksmanship	1.0	1.0	0.3
Sensor Range (pixels)	200	100	50
Broadcast Range (pixels)	500	500	500

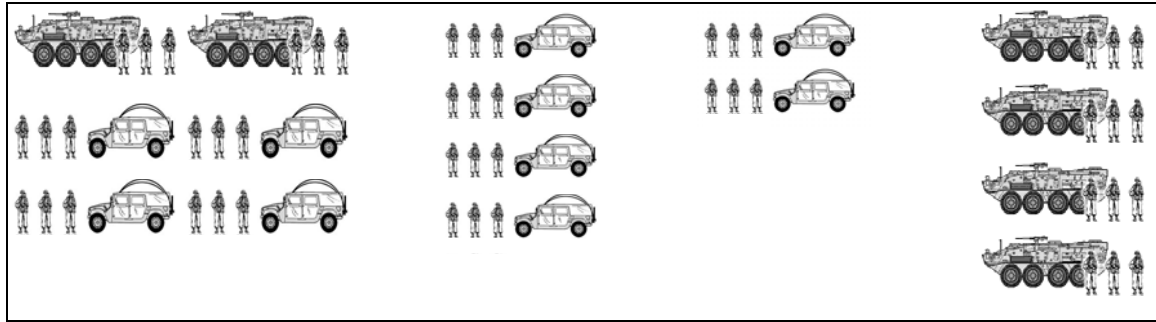
Table 4. Base, Camp, Base-House Attributes

⁴⁰ “Health” is an aggregate for all things that negatively affect an agent from accomplishing its goals. Some examples are physical health, stress level, fuel level, ammunition level, water level, rations level, wear on vehicles, etc. Edmund Bitinas, Zoe Henscheid, and Donna Middleton, *Pythagoras Users Manual*, v1.10, May 2006, Northrop Grumman Mission Systems, p. 24.

⁴¹ See the *Pythagoras User’s Manual* or Appendix B for details on the implementation of these values.

b. Patrol Agents

A patrol agent is an aggregate of two previously defined patrols. The composition of patrols for each scenario is shown in Figure 15 and a patrol's relative worth is shown in Table 5.



Div Patrol Agent

Bde Patrol Agent

Bde(-) Patrol Agent

QRF Agent

Figure 15. Agent Composition

	Division Patrol Agent	Brigade Patrol Agent	Brigade(-) Patrol Agent	QRF Agent
Marksmanship (Weapon Influence Factor)	0.5	0.7	1.0	1.0
Sensor Range (Situational Awareness)	100 (8.1 miles)	75 (6.08 miles)	50 (4.05 miles)	100 (8.1 miles)
Vulnerability (Force Protection Value)	0.1	0.3	0.8	0.0
Average Speed	4 (8 mph)	4 (8 mph)	4 (8 mph)	7 (14 mph)

Table 5. Relative Patrol Agent Worth (Key Parameters)

Patrols agents are divided into two shifts, namely daytime and nighttime patrols (see Figure 14). The shifts are controlled by state changes (triggers) within the agent behavior. All patrols start out with the same initial settings and initial behavior. At run start, day patrols transition to a patrolling status, whereas the night patrols transition to a 12-hour holding period. This holding period is not exact; it has a 30-minute tolerance on either side (288 ± 12 time-steps). It is impractical that all patrols would dispatch at exactly the same time, therefore the 30-minute variability was added (referred

to as “tolerance” within Pythagoras).⁴² Likewise, the time that patrols spend patrolling in the simulation is eight hours, with a variation of 30 minutes (192 + or – 12 time-steps). The 8-hour patrol time includes transit times out and back. This gives patrols several hours to complete debriefs and turnover to night patrols before finishing a 12-hour shift. The state change transitions of patrol agents are shown in Figures 16 and 17.

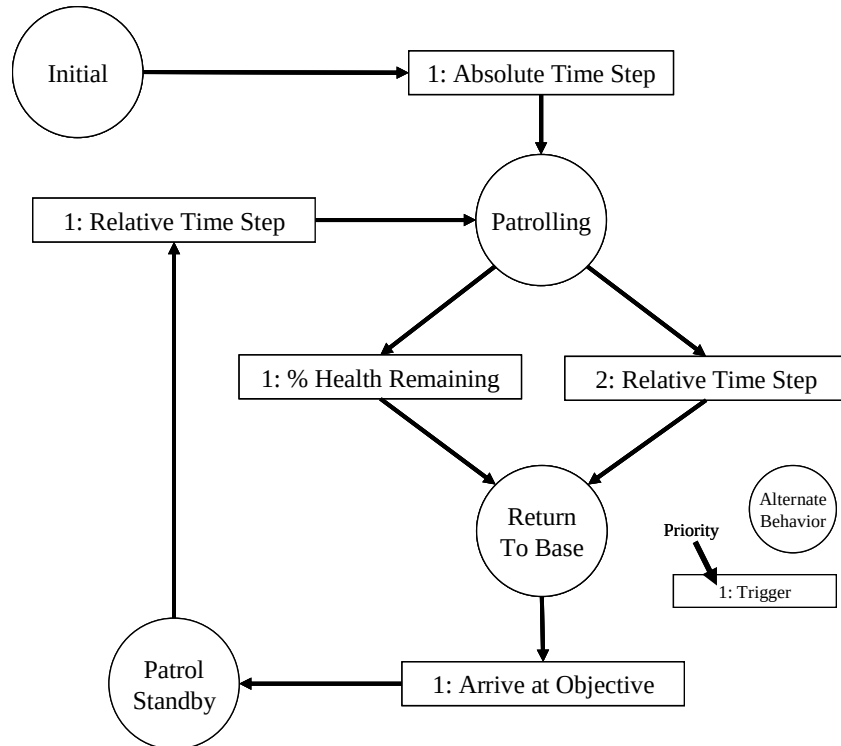


Figure 16. Day Patrol Agent Alternate Behaviors and Triggers

⁴² Almost all parameters within Pythagoras have “tolerances,” which are user-defined random variations to the assigned value of the parameter. Pythagoras refers to this as soft decision rules. “Pythagoras allows all decision variables and some human factors to be softened by the user. The approach is to reflect variation between individual agents by establishing a midpoint for the variable in question and then allowing the user to provide a uniformly distributed range around that value. Soft Decision Rules give each agent its own threshold within the fuzzy logic trade space but ensures traceability. It avoids the ‘everything is gray’ phenomena of fuzzy logic.” Edmund Bitinas, Zoe Henscheid, and Donna Middleton, *Pythagoras Users Manual*, v1.10, May 2006, Northrop Grumman Mission Systems, p. 24.

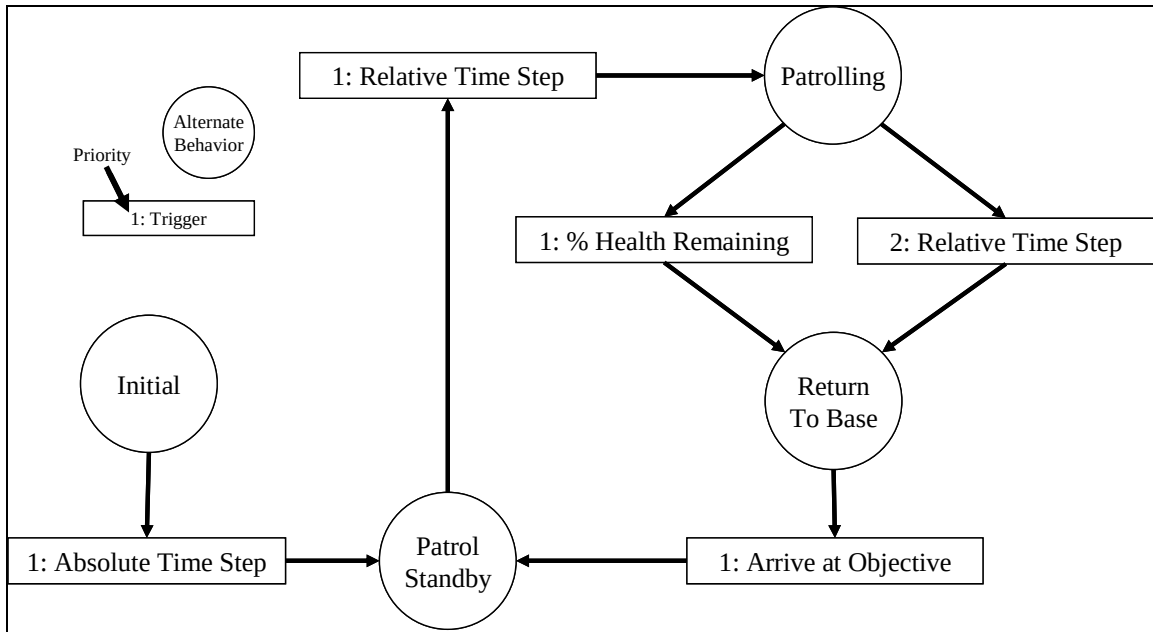


Figure 17. Night Patrol Agent Alternate Behaviors and Triggers

Patrol agents in all three scenarios have the same thresholds in “health” levels for altering behavior. At the 70% “health” level, patrols request assistance from patrols within their unit.⁴³ If their “health” is degraded to the 50% level, patrols request assistance from the QRF. If they are degraded to the 40% level, patrols will return to base (RTB). These thresholds are outlined in Figure 18.

	Agent Health Threshold
Request assistance from unit members	0.7
Request assistance from QRF	0.5
RTB	0.4

Figure 18. Patrol Agent Thresholds

c. Blue Force Agents: Quick Reaction Force (QRF) Agents

The QRF agents are the same in all scenarios. The composition of a QRF agent is shown in Figure 15 and key parameter values are shown in Table 5. The QRF responds to a patrol’s call for assistance when the patrol’s “health” reaches 50%. The QRF has an average speed of 14 mph (7 pixels per time-step) and is assumed to have overwhelming influence to subdue the situation. This means that the QRF can positively influence “events” and “insurgents” faster than they can be negatively impacted.

⁴³ Unit is defined as all the patrols operating from the same base. For example, all patrols operating from Eagle Base are considered to be in the same unit within the simulation.

However, the QRF can still be negatively impacted (health degraded) just like the patrol agents. Figure 19 shows the transition states of a QRF as it goes from its ready posture, to engaging with the enemy, to returning to base readying for the next deployment. A QRF in a real-world situation would rarely deploy repeatedly in a single day. After several hours of responding to a situation it would take time to rearm and refuel before the unit is in a ready status again. Within the model, one QRF agent is assumed to represent several forces within the reserve that would be able to deploy consecutively without the downtime to refit.

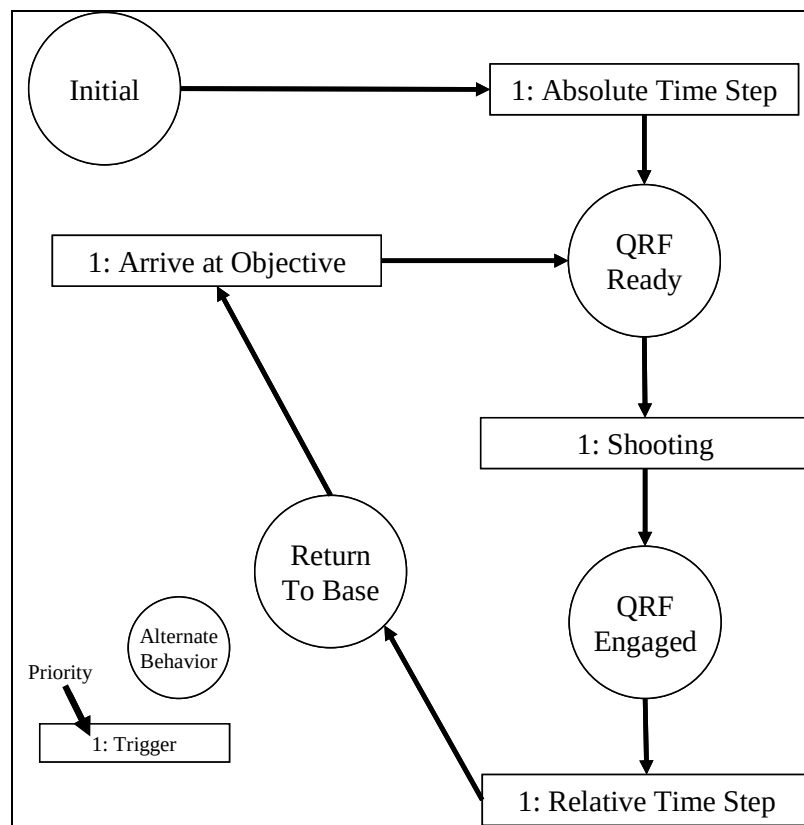


Figure 19. QRF Agent Alternate Behaviors and Triggers

d. Red Force Agents: Insurgent Agents

Insurgent agents, as they are referred to in the model, are the hostile actors that are opposed to the U.S. mission of achieving stability. Their general goal is to disrupt U.S. actions in an aim to exert influence over the population and persuade them in resisting U.S. efforts in stabilizing the region. The insurgents are opposed to the terms of the peace agreement under which U.S. forces are operating.

There is only one insurgent agent class created within the model; however it has varying number of instances based on the threat level. Each instance of the agent is randomly distributed on the terrain map at the start of each model run. The random distribution is representative of the unknown size and disposition of an insurgent threat.

Each instance of the insurgent agent should be thought of as an aggregate of a cell of insurgents operating in unison. The individual cells (agents) exchange information on blue force locations within the simulation. All of the cells have the same desire of attacking a blue patrol when they outnumber them. These attacks are primarily harassment attacks, being that they do not have sufficient firepower to destroy a patrol. The “insurgent” agent’s highest desire is to cluster with other insurgents and then seek out the nearest lone blue patrol. This follows the commonly used tactic of seeking out individual units and attacking with a force ratio advantage. Insurgents will not become decisively engaged and will retreat from an engagement when their strength drops below 25%.

e. Escalation Agents

Escalation agents represent the intensification that can occur with an event when there is a lack of a PK presence. For example, if a demonstration occurs and there is no response from a PKF, it could quickly escalate into a violent demonstration or even a full-scale riot. Likewise, a patrol could respond to an event and subdue the situation, however, if there is not another force presence for some time, the situation can become inflamed again.

The escalation agent is an important piece of the cause and effect of force presence. These agents can view the full simulation environment, but are unknown to all other agents.⁴⁴ Escalation agents “escalate” the situation by restoring “health” to other red agents with a restorative weapon. However, this can only be accomplished in the absence of patrol agents, due to their propensity to avoid any blue agent. The rate at which an escalation agent can restore health to a red agent is roughly equal to a patrol’s ability to deplete a red agent’s health. Escalation agents have no bearing on the behavior

⁴⁴ Escalation agents have a 0.0% detectability on all sensor signature bands. This makes the Escalation agents invisible to all the other agents’ sensors.

of other agents because they are not detectable by any of their sensors. Essentially, they are invisible in the simulation. Their only purpose is to restore health to Event and Insurgent agent's in order to represent an escalation in the threat environment.

f. Event Agents

There are ten different variations of event agents corresponding to the ten levels of severity as described in Chapter 1. Each threat level within the simulation has a set number of each of the ten types of event agents. The higher the threat level, the more rigorous events occur.

Event agents are stationary within the simulation. Once an event is discovered by a blue patrol, that location is known throughout the duration of the run. Although events would never be stationary in a true operation, it works for the low resolution of the model since they mutually view each other as enemies. If events were allowed to move, it would result in patrol agents chasing around after them. This behavior would not capture the behavior of a patrol moving to an assigned area to respond to a situation.

Event agents are an abstraction of actions by hostiles, neutrals, and friendly forces. Although the "event" agents are referred to as "red" agents, they represent any situation that requires a patrol's time, energy, and resources to respond to. Examples of actions are: a hostile action is a riot, a neutral action is negotiating with local authorities, and a friendly action is gathering information.

Events are given "agent target values" according to the severity (level) of the event. The higher the level of the event, the higher the target value assigned, as shown in Table 6. The agent target value allows the blue patrols to prioritize between the events. If a patrol senses two separate events occurring within its AOR it will respond to the one with the higher target value. This captures the ability of U.S. forces being able to distinguish, categorize incidents occurring, and then prioritize the response to them.

S e v e r i t y ↓	Event	Agent Target Value	Marksmanship	Vulnerability
	Event1	100	0.10	1.00
	Event2	200	0.20	0.90
	Event3	300	0.30	0.80
	Event4	400	0.40	0.70
	Event5	500	0.50	0.60
	Event6	600	0.60	0.50
	Event7	700	0.70	0.40
	Event8	800	0.80	0.30
	Event9	900	0.90	0.20
	Event10	1,000	1.00	0.10

Table 6. Event Agent Parameters

All “event” agents have an influence weapon with a maximum range of 1,300 meters (20 pixels) and an effectiveness of 0.0050. Likewise, all event sensors’ maximum range is 1,300 meters, with a broadcast range of 1,300 meters. The variability in the influence weapon’s effectiveness is introduced by the individual agents “marksmanship” ability. The higher the marksmanship parameter, the more likely they are to hit their target. Therefore, this parameter is used as a measure of the event’s severity by how much influence it can impart on patrol agents. The other measure of the severity of an event agent is its “vulnerability” parameter setting. The higher the setting, the easier it is for a patrol to positively influence (kill) the event. As shown in Table 6, the relationship is linear between the most severe event (Event10) and the least severe event (Event1).

Red agent weapons negatively impact blue agents. When a patrol is engaged with an event to positively influence it, the event is negatively impacting the patrol with its influence weapon. The longer the duration of engagement with an event, the more vulnerable a patrol becomes to suffering a casualty. The duration of these interactions is measured in the simulation with a generic attribute. Every time-step red and blue agents are engaged, an amount of generic attribute is added with each shot from the influence weapons. The attribute accumulations conceptualize the reality of longer duration incidents putting patrols at a greater risk of suffering a casualty. More severe events also result in more stress on the patrol, depletion of fuel and possibly ammunition, wear and tear on vehicles, etc. All these impacts on the patrol are rolled into the patrol’s

“health.” As previously discussed, patrols have thresholds that alter their behavior based on their “health” level. For a further explanation and examples of what the “event” agents represent, see Appendix B.

2. Data Sources, Abstractions, Assumptions, and Validations

a. Data Sources

Much of the data used to create the model were drawn from interviews with officers who served in Bosnia during SFOR. Doctrinal publications were used for references, which can be found under works cited. Since many of the concepts in the model are abstract in nature, objective data sources do not always exist. Some of the concepts were based on expert opinion, while some were based on the modeling capabilities of Pythagoras. All values for the abstract parameters can easily be adjusted to fit different circumstances and beliefs. The overall intent of concepts to be modeled had to be compatible with what is possible in Pythagoras. The important abstract parameters within the simulation are discussed below.

b. Abstractions

The two major abstractions in the simulation are an agent’s situational awareness (SA) and influence projection. These two concepts are captured with the sensors and weapons in Pythagoras.

c. Abstraction – Sensors

Agent sensors are used as an abstraction of an agent’s SA. The SA of patrol in a stability operation is developed from human senses (individual observation), equipment sensors (i.e., thermal imagery and night vision equipment), intelligence, surveillance, and reconnaissance (ISR) sensors, and intelligence briefs, communications, etc. For red forces, SA is developed in much the same way, but with a lesser degree of technological equipment. However, with a linked network of collaborators and cell phones, insurgents can maintain the same SA level—or higher—as blue forces. This is because insurgents are operating in familiar terrain.

The SA for red agents is constant throughout all three scenarios, however, SA varies for the differing blue force levels. The larger the PKF, the more enabling

troops they have and therefore have better ISR capability. This gives patrols better SA. As the force downsizes, the less enablers they have and the SA goes down. For specifics on sensor parameter settings, see Appendix B.

d. *Abstraction – Weapons*

There are two types of weapons used in the model: influence weapons and restorative weapons. The influence weapons have two effects when fired. First, they degrade the “health” of the targeted agent as a measure of influencing that agent. Second, they impart a level of “attribute” on the targeted agent as a measure of the intensity of the interaction (engagement). Both of these effects are based on the duration of the engagement. The influence weapon is a lethal weapon that conceptualizes having an influence over another agent. It is referred to as lethal because it degrades a targeted agent’s health. However, as previously discussed, health level is a surrogate for influence level in the model. Blue agents influencing red agents actually “kill” them (deplete all their health) with a lethal weapon in the simulation. Once an agent is killed it is considered to be influenced; however, the agent can be restored with restorative weapons. When an agent influences another agent it is considered to be a perceived change in the threat environment. The more red agents blue can influence, the more stable the environment becomes. When red negatively influences blue, the opposite is true; the threat environment increases and the situation becomes less stable. This results in more effort for the patrols to reestablish security and stability.

QRFs and Base agents also have restorative weapons that can restore health back to patrol agents. This represents a patrol receiving support from a reinforcing QRF, or resting, rearming, and reequipping at a garrison location. The restorative weapons only restore the patrol’s “health.” The “attribute” levels that patrols accumulate through engagements are cumulative throughout the duration of the simulation.

Red forces shoot lethal weapons that inflict damage on blue in much the same way. This damage (depleted health) sustained by blue represents a negative impact that delays them in accomplishing their mission. Blue agents modify their behavior when targeted by a red agent.

The damage inflicted on an agent (amount of health subtracted from agent) is a function of several multipliers.⁴⁵ Most of the multipliers are held constant, while others are varied to distinguish relative influence power of various agents. Since the weapon is an abstraction of the idea of exerting influence, the parameter settings within Pythagoras have been simplified as much as possible. The only parameters varied for damage inflicted are the shooting agent’s “marksmanship” and its weapon’s range, and the targeted agent’s “vulnerability.” Table 7 outlines the varied parameters and those held constant.

PARAMETERS VARIED
Shooting Agent’s Marksmanship (0.00 to 1.00)
Targeted Agent’s Vulnerability (0.00 to 1.00)
Maximum weapon range (varied depending on how far an agent can project influence)
PARAMETERS HELD CONSTANT
Fire Rate (1 shot per time-step)
Weapon Effectiveness (1.000, completely effective)
Weapon Probability of Hit (1.000 out to maximum range of weapon)
Weapon Probability of Kill (1.000 out to maximum range of weapon)
Degree of Random Damage (0.000, deterministic)
Protection Offered by Terrain (0.000, no protection)

Table 7. Parameters of Damage Function in Pythagoras

This set up of weapon usage allows variability in influence projection of individual agents by varying that agent’s marksmanship. This required only one “patrol weapon” to be created for “patrol” agents. The amount of influence (damage) a patrol can exert was varied by the individual agent’s “marksmanship.”

The “vulnerability” setting of an agent determines how resilient it is to the “influence weapons.” The larger patrols are assumed to have a greater force protection factor and are therefore more resilient than the smaller patrols. The variations in event “vulnerability” is representative of the wide range of events that patrols respond to. The higher-level events require a great deal of damage to influence (kill) and therefore have a very low vulnerability. Then there are those events that are relatively minor (e.g., meeting with local authorities). These are easier to effect change and therefore have a

⁴⁵ For the all the damage functions used within Pythagoras, see the *Pythagoras User’s Manual*, pp. 59-61.

higher vulnerability (i.e., they are “killed” easier). Another way to view this concept is a force protection factor that is one minus vulnerability. For a list of weapons used in the simulation see Appendix B.

e. Assumptions

For the abstracted concepts in the model to be relevant, a number of assumptions are made. Many of these assumptions were required when constructing the scenarios within the Pythagoras model. The first underlying assumption is that presence equals security which equals stability. Patrols were built with the assumption that their physical presence exerts influence to calm and stabilize the situation. A study of SFOR Lessons learned recommended to “continue to conduct presence patrols and missions.”⁴⁶ It further stated,

The international community unanimously agreed that SFOR’s most valuable function to date has been the presence of their roving patrols and positioning troops at contentious sites at critical times. An SFOR presence not only serves to deter unlawful acts by former warring factions, but it also deters overt violent acts by members of the obstructionist power structures.

The presence of stationary and patrolling troops has proven particularly useful to assist with elections, exhumations (war crime scene investigations), displaced persons and refugees (DPRE) returns, unlawful residents (squatters) evictions, and to allow farmers (of differing ethnicity) to tend their fields. British forces brought the concept of ‘surge operations’ from Northern Ireland and have used this approach effectively in Bosnia.⁴⁷

If the assumption of presence is accepted, the follow-on question raised is how much presence? Most people assume that the larger the presence, the better. However, smaller patrols are more accessible in many cases to interact with and influence the population. This is primarily because smaller patrols are more approachable by the common civilian. In addition, utilizing smaller patrols allows a commander to generate

⁴⁶ United States Army Peacekeeping Institute, “SFOR Lessons Learned, In Creating a Secure Environment with Respect for the Rule of Law; Based on a Study of Bosnia,” Issue 23, May 2000, p. 34. http://www.au.af.mil/au/awc/awcgate/army-usawc/sfor_rule_of_law.pdf#search=%22SFOR%20Lessons%20Learned%2C%20In%20Creating%20a%20Secure%20Environment%20with%20Respect%20for%20the%20Rule%20of%20Law%22. Last accessed on 28 August 2006.

⁴⁷ Ibid.

more patrols to blanket the countryside, and disperse the stabilizing presence. What mitigates the risk of using smaller patrols is the implied presence of an effective reaction force responding quickly.

In this research, smaller patrols are given a greater influence factor than the larger patrols. The relative influence factors (agent marksmanship) can be seen in Table 5. The argument can be made that this is counterintuitive. If smaller patrols are more effective in a stability operation, why don't larger forces employ smaller patrols? The answer is that the security situation dictates what the commander mandates as standard operating procedure (SOP) for a patrol size. Therefore, a commander will not employ smaller patrols until he feels the threat level is acceptable to do so. As the threat environment improves, a smaller-sized patrol is better accepted within the community and more approachable for individuals providing information. Therefore, the assumption is made that a smaller patrol wields greater influence on events.

The influence power differences of the various-sized patrols also support the assumption that a smaller force can handle the same level of activity as a larger force, although it will take more time. This assumption is the original hypothesis—that there exists an identifiable “trade-space” where a smaller force can assume the mission without assuming greater levels of risk. It is then assumed that the success of the mission will take more time.

Testing our hypothesis or identifying the various “trade-space” in the threat continuum is obviously the difficult part of the research. Every stability operation in the past has used different metrics for the threat environment. Although a difficult thing to do, this study relies on the assumption that the actual threat environment can be measured with some degree of accuracy. Most of the measurements are based on relative trends. For example, a report from The Brookings Institution on Iraq records trends in such areas as crime and unemployment. In all, the report tracks 55 security indicators (variables) in assessing the threat environment.⁴⁸ Trends like the number of attacks this month compared to last month give indications of improving or deteriorating threat

⁴⁸ Michael E. O'Hanlon and Nina Kamp, “Iraq Index, Tracking Variables of Reconstruction and Security in Post-Saddam Iraq,” The Brookings Institution, July 31, 2006, www.brookings.edu/iraqindex, p. 2. Last accessed on 28 August 2006.

environment. Individually, measurements might not be accurate, however, when measurements are considered together (all source fusion), it is assumed that they provide a level of accuracy that is acceptable toward measuring the threat environment.

If it is accepted that the threat environment can be measured, then the goal is to provide a methodology for the downsizing decision thought process with consideration to the threat environment. The model development outlined in this chapter assists in structuring a methodology to support such a decision.

Although not directly included in the model, a force downsizing also assumes that host nation security forces are more capable in managing the security of their country. As stated in FM 100-15, the ultimate objective of postconflict operations is, “the smooth transition of responsibility back to civil authorities.”⁴⁹ The benefit from the commander downsizing the force is it helps in accelerating the responsibilities of the civil authorities. If effective, U.S. forces will be able to depart the region. Of course, there is always a possibility of increased risk anytime a force is downsized. The greatest risk to mission success/failure is in the context of casualties incurred, resources available (troops), and duration of operation (time). The sooner a commander can effectively downsize minimizes the exposure to threats. Protracted operations can risk overstaying their welcome and thereby risk reversing the established stability. Eventually, the local population will find discontent with a PKF if they are viewed as indefinite occupiers.

f. Validations

ABMs are typically not validated models in the official context. Within the scenarios of this research, there are enough abstractions that make it impossible to validate it as a bona fide representation of the real world. However, there is a significant amount of face validation by subject matter experts. This is done in nearly all M&S studies. In this research, a number of Army and Marine officers who have participated in Stability Operations reviewed the simulation to ensure that it is a good representation of the real-world concepts being modeled. The behavior demonstrated by the various agents was carefully scrutinized throughout the creation of the three scenarios at the Project

⁴⁹ Headquarters, Department of the Army, FM 100-15, Corps Operations, 29 October 1996, p. 3-17, <http://www.globalsecurity.org/military/library/policy/army/fm/100-15/index.html>. Last accessed on 28 August 2006.

Albert International Workshop (PAIW). Any aberrations in behaviors were adjusted based on the consensus of the PAIW group. In essence, the rigorous “face” validation applied to the model closely adheres to DMSO definition of validation given below.⁵⁰

3. Summary

This chapter covered the mechanics of constructing the three scenarios used for analyzing the problem statement. In addition, this chapter described how the scenarios are implemented into the Pythagoras MAS. Chapter III covers the experimental design methodology. This is the methodology for running the simulation so as to produce useful data to analyze; that is, identifying where the “trade-space” exists within the threat continuum.

⁵⁰ **Validation:** The process of determining the degree to which a model or simulation is an accurate representation of the real-world from the perspective of the intended uses of the model or simulation. The Defense Modeling and Simulation Office Glossary, https://www.dmsomil/public/resources/glossary/results?do=get&search_text=validation. Last accessed on 28 August 2006.

III. DESIGN OF EXPERIMENT

A. OVERVIEW

After discussing the development of the model in Chapter II, this chapter describes the design of experiment used to explore the model. Once scenarios are created within the MAS (referred to as the “model”), an analyst applies a methodology to properly select parameters and their values for the experiment. In this case, the experiment refers to running the model thousands of times on a supercomputer with the varied parameters and analyzing the results. The whole experiment relies on using a design that is both efficient and suitable for generating useful data. The following sections cover the two designs used in the experiment. In addition, this chapter provides a brief explanation on the designs implemented in the data-farming environment at the Maui High Performance Computing Center (MHPCC).

B. PARAMETERS EXPLORED

The focus of this research is on exploration of the threat environment and how a blue force performs in various threat environments. Therefore, the selected factors in the various experimental designs utilize the parameters that defined the threat continuum. More specifically, the parameters that define the threat environment are the number (instance) of each type of “red” agent. The “red” agents consist of ten levels of “event” agents, “insurgent” agents, and “escalation” agents. Two separate designs, a custom design and a space-filling Nearly Orthogonal Latin Hypercube (NOLH) design, are used to explore the effects that varying threat environments have on the performance of the PKF in each of the three scenarios.

C. MANUALLY CONSTRUCTED DESIGN (CUSTOM DESIGN)

The first design considers a total of 100 events occurring within each of the three scenarios. The 100 events are distributed amongst the ten levels of events according to the threat continuum shown in Figure 20.

Threat Level	Event1 Agents	Event2 Agents	Event3 Agents	Event4 Agents	Event5 Agents	Event6 Agents	Event7 Agents	Event8 Agents	Event9 Agents	Event10 Agents	Insurgent Agents	Escalation Agents
1 -->	15	16	17	18	19	5	4	3	2	1	1	1
2 -->	14	15	16	17	18	6	5	4	3	2	2	2
3 -->	13	14	15	16	17	7	6	5	4	3	3	3
4 -->	12	13	14	15	16	8	7	6	5	4	4	4
5 -->	11	12	13	14	15	9	8	7	6	5	5	5
6 -->	10	11	12	13	14	10	9	8	7	6	6	6
7 -->	9	10	11	12	13	11	10	9	8	7	7	7
8 -->	8	9	10	11	12	12	11	10	9	8	8	8
9 -->	7	8	9	10	11	13	12	11	10	9	9	9
10 -->	6	7	8	9	10	14	13	12	11	10	10	10

Figure 20. Agent Distribution for Threat Levels 1 Through 10

This design is based on the idea that the distributions of events patrols respond to are not linear. The design matrix in Figure 20 is the distribution of events that patrols respond to in the ten threat levels. In a real stability operation, it is likely the threat environment is composed of many low-level events and fewer of the high-level events. It is likely that the distribution of these events is nearly linear. Normally, there are a lot of minor, low-level events occurring and fewer of the more severe, high-level events occurring. An example is shown by the dashed red line in Figure 21.

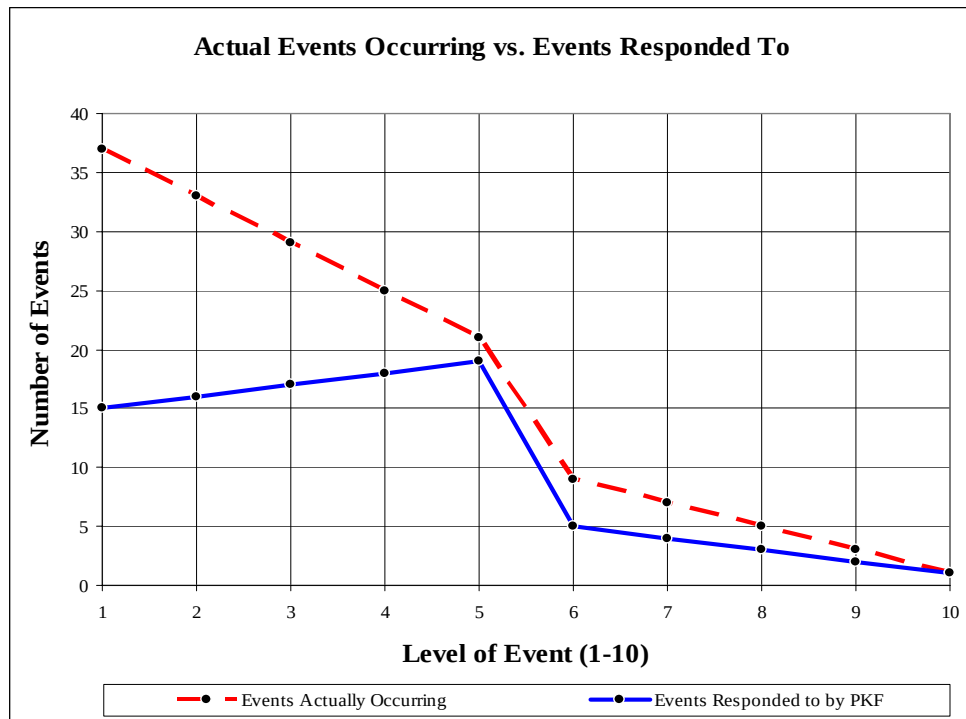


Figure 21. Representation of Possible Events Actually Occurring Compared to Those Events the PKF is Able to Respond to

However, the types of incidents actually occurring and those responded to by a PKF are different. There are simply too many low-level events for a PKF to know about and/or respond to. For that reason, it is assumed that a majority of the “events” that a PKF responds to fall in the middle of the spectrum of events. An example of this is the blue line in Figure 21, which is the distribution of events for threat level 1, as defined in Figure 20. The distribution of all ten threat levels from Figure 20 is shown in Figure 22. Figure 22 highlights how the distribution of events that patrols respond to fall off linearly from the middle range of “Event 5” and “Event 6” agents. This is considered the threshold from peacekeeping (0-5) to peace enforcement (6-10).

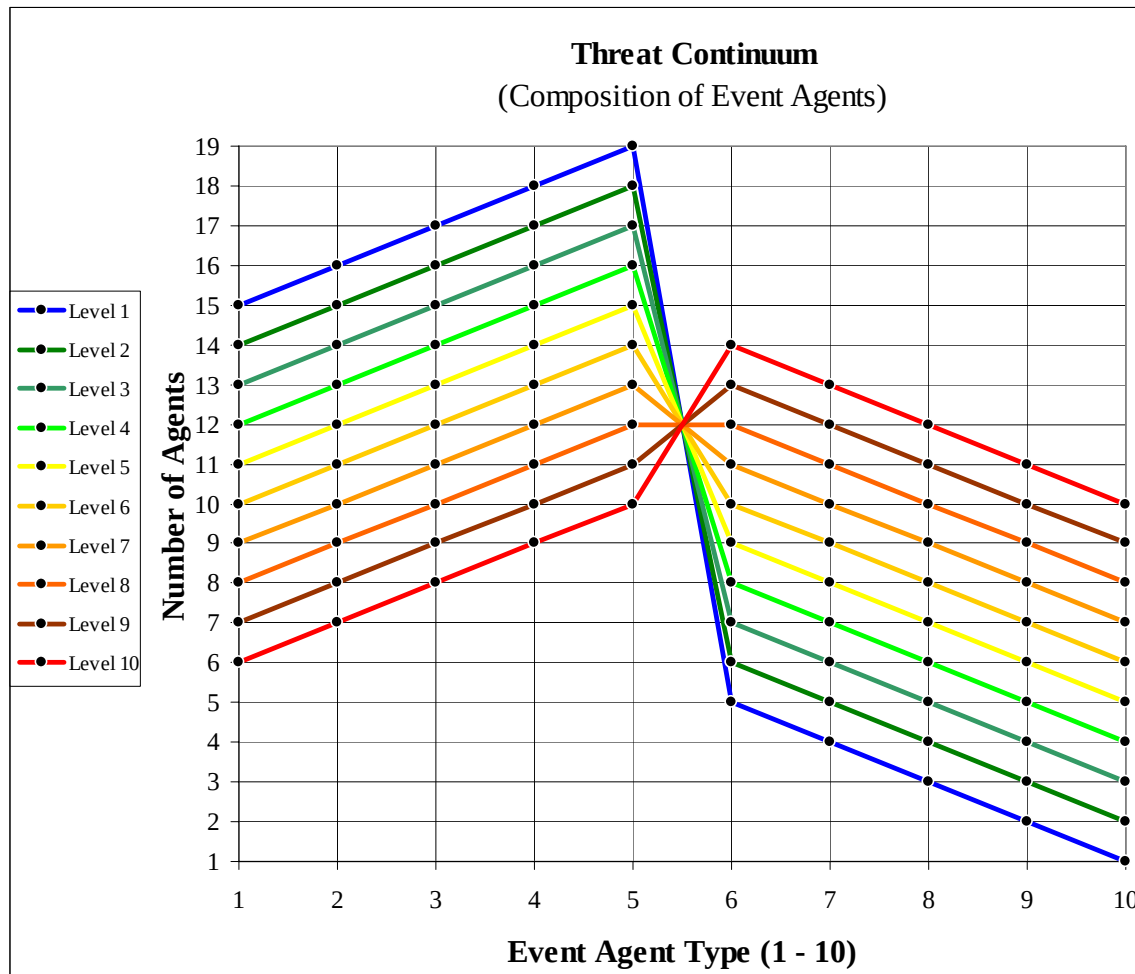


Figure 22. Distribution of “Event” Agents Patrols Respond to; Each Level Sums to 100 Events

This distribution holds because a PKF can not have knowledge of all the minor events occurring. As events become more serious, it is likely they have greater visibility. Therefore, the PKF would be aware of it and would respond to it.

Returning to the assumption previously made, that force presence equates to security, supports the idea of the diminished numbers of low-level events that patrols respond to. This is because the mere presence of a force in theater may be sufficient to deter some low-level events from even occurring. Basically, the PKF would have a calming effect just by being in country without actually responding to an incident. The mid- to high-level events are not as easily deterred as the low level and, as such, more of them occur and must be responded to.

In addition to the “event” agents, each threat level has a number of “insurgent” and “escalation” agents that increase linearly from 1 to 10. In this design, each threat level (combination of “red” agents) is considered a design point. A design point is the parameter settings at the start of a simulation run. Parameter settings in the model not defined in a design point are held constant through all model runs. The design point only defines those parameters that are varied in order to make comparisons on the outcome of the simulation.

D. SPACE-FILLING DESIGN (NEARLY ORTHOGONAL LATIN HYPERCUBE (NOLH))

The custom design previously described is only one possibility of what the composition of a threat continuum might look like. Therefore, a larger, space-filling design is used as the second experimental design. This design considers a wider range of possible combinations of the red agents that make up the threat continuum. A space-filling design refers to extensive coverage of the possible combinations of parameter settings within the multidimensional design space. The space-filling design allows sensitivity analysis to be conducted to determine which factors have the greatest effect on the outcome of the simulation.

To completely cover a design space, an analyst could use a gridded or full-factorial design. These designs consider every possible combination of selected parameters. The problem with a full-factorial design is that it severely limits the number of factors (parameters) and levels (parameter settings) that can be simultaneously examined due to the exponential growth of these designs. For example, this research

considers 12 factors (all “red” agents) at 21 levels (0-20 instances for each agent). A gridded design would require 7,355,827,511,386,641 ($\# \text{ Levels}^{\# \text{ Factors}}$ or 21^{12}) design points. We desire to replicate each design point a minimum of 30 times to be able to assess its variability. This yields a total of 220,674,825,341,599,230 simulation runs. At approximately 40 minutes per simulation run, this would take over 16 trillion years for a single CPU to run. It is clear that full-factorial designs are simply not feasible with many factors and levels, even with the power of super computers. Figure 23 highlights the number of required design points for full-factorial designs. This emphasizes the fact that due to exponential growth, “ 2^{100} is forever.” A simulation design with 100 factors at 2 levels (binary) (1,267,650,600,228,229,401,496,703,205,376 design points), utilizing all the super computers in the world, would literally take forever to run.

# 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	<i>Don't even think about it!</i>	5 ²⁰ = 95 trillion	2 ²⁰ = 1,048,576
40		5 ⁴⁰ = 9100 trillion trillion	2 ⁴⁰ = 1.1 trillion

Figure 23. Number of Required Simulation Runs in Various Gridded Designs⁵¹

By comparison, an NOLH design⁵² can achieve adequate combinations of factor levels with just 257 design points. Replicating each design point 30 times yields a total of 7,710 simulation runs per scenario. At an average of 40 minutes per run, the total time required is 5,140 CPU hours per scenario. To further emphasize the efficiency of the NOLH designs, Table 8 shows a comparison number of design points for various factors

⁵¹ Professor Susan Sanchez, Course OA4333, Simulation Methodology, 14 February 2006, Naval Postgraduate School, Monterey, CA, course slide #17.

⁵² Thomas M. Cioppa, LTC, USA, “Efficient Nearly Orthogonal and Space-Filling Experimental Designs for High-Dimensional Complex Models,” Ph.D. Dissertation, Operations Research Department, Naval Postgraduate School, Monterey, CA, 2002, p. 5.

and factor levels. Random Latin Hypercube designs can be generated for arbitrary combinations of number of factors (k) and number of runs (n), as long as $n \geq k$.⁵³

Number of Factors	Number of Runs
2-7 factors (up to 17 levels/factor)	17
8-11 factors (up to 33 levels/factor)	33
12-16 factors (up to 65 levels/factor)	65
17-22 factors (up to 129 levels/factor)	129
23-29 factors (up to 257 levels/factor)	257

Table 8. Number of Required Simulation Runs in Various NOLH Designs

To graphically display the space-filling properties of the NOLH in multidimensional space, Figure 24 displays a two-dimensional depiction of the space filling. By comparison a full factorial scatterplot like Figure 24 would be completely blacked out by considering every combination of red agents. Gridded designs do provide greater granularity on the interactions among all factors; however, the fidelity achieved by the NOLH is more than adequate for conducting analysis on the critical factors. And most important is the efficiency in which the NOLH provides adequate coverage. The intent with this design was to look at the full range of a threat spectrum by considering a full range of “red” agent combinations. Like the custom design, this design only considers “red” agent instances from a minimum value of 0 to a maximum value of 20. Unlike the custom design, this design does not specifically define what combinations of red agents constitute threat levels 1 through 10. Instead, this design considers a wide mixture of combinations of red agents so that analysis can be done on which agents have the greatest impact on the outcome of the simulation.

⁵³ Professor Susan Sanchez, Course OA4333, Simulation Methodology, 14 February 2006, Naval Postgraduate School, Monterey, CA, course slide #17.

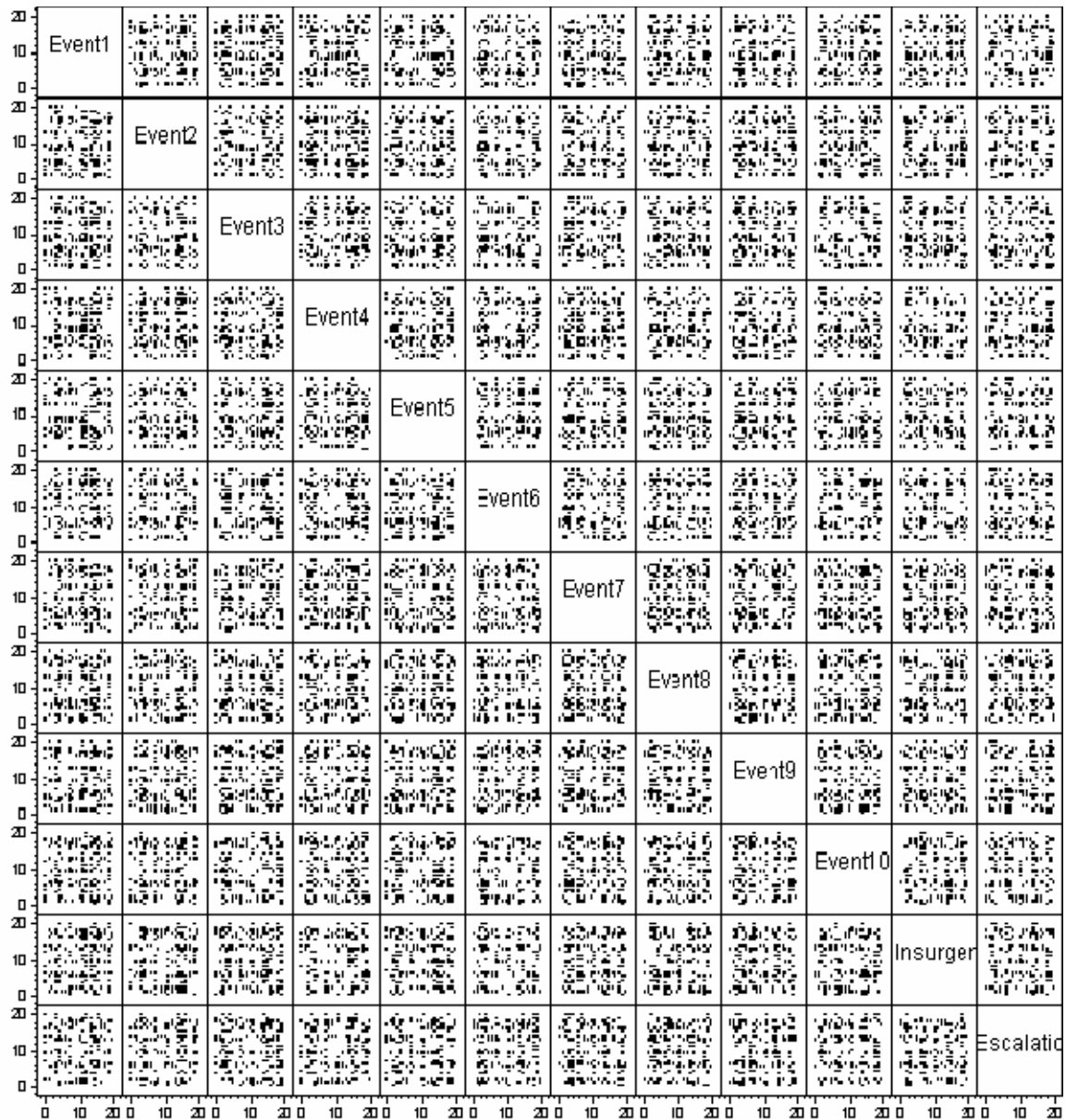


Figure 24. Scatterplot of NOLH Design Points (Red Agent Instance 0-20)

E. DATA FARMING AND SUPER COMPUTING

Even with the efficiency of the NOLH design, to run our model thousands of times requires super computing capability. This research utilized the computer cluster at the MHPCC. This capability is available to Naval Postgraduate School (NPS) students through the Simulation, Experimentation, and Efficient Design (SEED) Center's

affiliation with Project Albert and the MCWL.⁵⁴ Project Albert contracts with MHPCC to run the suite of MAS within the Project Albert community to conduct data farming.

Data Farming is the process of using a high performance computer or computing grid to run a simulation thousands or millions of times across a large parameter and value space. The result of Data Farming is a ‘landscape’ of output that can be analyzed for trends, anomalies, and insights in multiple parameter dimensions.⁵⁵

To conduct data farming, each design point of an experimental design needs multiple replications to apply the central limit theorem⁵⁶ or the law of averages. A rule of thumb used for a minimum number of replications per design point is 30, which allows the application of the central limit theorem.⁵⁷

The custom design only has ten design points, so it is feasible to run each design point 100 times. This gave a lower variance to the estimates of the means of the end of run MOE data. Since the NOLH is fairly large compared to the custom design, each design point was only replicated 30 times. The duration of one run, number of design points, and the required turn-around time dictates how many replications per design point are run. If a design point is only run once, an analyst will not have confidence in the results. Due to the stochastic nature of MAS, it is possible that the one run could be an outlier compared to the average of many runs. Replicating the simulation multiple times for each design point allows all the variations in the MAS to average out, resulting in a higher level of confidence in the data. Table 9 shows the number of replications run for each design and the estimated processor time.

⁵⁴ The Simulation, Experimentation and Efficient Designs (SEED) Center, in the Operations Research Department at the Naval Postgraduate School, Monterey, CA, supports students conducting research in modeling and simulation.

⁵⁵ http://en.wikipedia.org/wiki/Data_farming. Last accessed on 22 July 2006.

⁵⁶ The distribution of an average tends to be Normal, even when the distribution from which the average is computed is non-Normal.

⁵⁷ Jay Devore, *Probability and Statistics for Engineering and the Sciences*, 6th Edition, Canada: 2004, Brooks/Cole, p. 240.

	Custom Design	NOLH Design
Design Points	10	257
Replications per	100	30
Simulation Runs	1,000	7,710
Number of Scenarios	3 x 5 = 15	3
Total Simulation Runs	15,000	23,130
Average Runtime	40 Minutes	40 Minutes
Total CPU Time	10,000 Hours	15,420 Hours
	416.6 Days	642.5 Days

Table 9. Simulation Runtimes for Manual and NOLH Design

F. SIMULATION DURATIONS

In order to identify the “trade space” (when a smaller force can assume the mission of a larger force), the three scenarios are run for different durations. Ideally, each simulation would be run for one long duration (10 days or 5,760 time-steps) with MOE data collected every day (576 time-steps). This is referred to as time series MOEs within Pythagoras. Unfortunately, this capability is not enabled for the data-farming environment at the MHPCC. As a work around, each scenario was run 5 different times utilizing the custom design. Each scenario was run for a 2-, 4-, 6-, 8-, and 10-day duration, with MOE data recorded at the end of the run. This results in 15 different model runs, as shown in the number of scenarios row in Table 9. In each of the model runs, the same random number seeds were used so that each simulation is a continuation of previous runs. For example, the data collected at the 4-day duration is a continuation of the same simulation that is collected from the 2-day duration run. For data analysis, the end of run MOE data was compiled. This compiled data set is the same as if time series MOEs had been collected, however, it just took much more computing time because each model run was only contributing the last two days of new data.

The space-filling design was applied to each of the three scenarios. Each scenario was run for a 10-day duration (5,760 time-steps) with end of run MOE data collected. Unlike the custom design, it was not necessary to run the NOLH design for 2-, 4-, 6-, 8-, and 10-day duration to collect time series MOEs. This is because specific threat levels are not identified within the NOLH design. This design was used to compare parameters of each scenario and determine the impact on the simulation outcome.

G. SUMMARY

The designs described in this chapter are the basis for the research results. The following chapter discusses the data analysis based on the custom design and the NOLH design at the MHPCC. After the data analysis is covered, conclusions are drawn and recommendations proposed in Chapter V.

IV. DATA ANALYSIS

A. OVERVIEW

This chapter discusses the analysis of the data from the custom and the space-filling designs described in Chapter III. The simulation results from the space-filling design (NOLH) are discussed first, followed by the custom design.

Results from the space-filling design are used to explore the effects each parameter has on the outcome of the simulation. With those results in mind, results from the three different scenarios run on the custom design focus on two areas: mission failure risk and force protection risk. It is these two MOEs that are under consideration in identifying the trade-space of a force downsizing. Since the trade-off in identifying the trade-space is time, only the data from the custom design is used.

First, the data from the scenarios run with the custom design are compared on the area coverage achieved by each force level. Area coverage is the measure of mission success, which measures how the force is able to project their presence and stabilize the region. The MOP for mission success is how many red agents blue is able to positively influence. Mission failure risk is one minus the mission success rate. If a force achieves 90% area coverage, then the measure for mission failure risk is 10%. This does not imply that a PKF fails if it does not achieve 100% area coverage; it says that the higher the mission failure risk, the more likely the PKF is to fail their mission of presence and spreading stability. This ties into the main assumption that presence equates to security, which eventually leads to stability. If presence is not achieved at a sufficient level, stability will not be achieved. The level of sufficient presence is a subjective measure and therefore the MOE is interpreted as the greater the area coverage (presence), the better.

B. DATA CLEANING

Results from data farming runs at the MHPCC are returned as .csv files (comma separated value files). These files contain the values selected as “end of run MOE” values within Pythagoras. For a list of specific end of run MOEs recorded, see Appendix B.

Each file requires some “cleaning” to consolidate it into a useful format. To do this, the .csv files can be opened in any data analysis software. Microsoft Excel 2003 and SAS JMP 5.1 were used to conduct the analysis. Within JMP, data from each scenario was combined to give useful columns of MOE data. For example, when considering the area coverage, the values of “final dead” from each red agent class had to be combined to get the total number of red agents killed in each simulation. The number of red agents “killed” (influenced) divided by the total number of red agents provided the area coverage achieved by blue. Area coverage is the metric used for mission failure risk. The process of combining individual agent class data was repeated for the force protection risk MOE. Each of the individual injured patrols within each patrol agent class was combined and divided by the total number of patrols. The percentage of injured patrols is used as the metric for the force protection risk MOE. The process of data cleaning is repeated for all 18 scenarios (15 run with the custom design and 3 run with the NOLH design) for data useful in measuring mission failure risk and force protection risk.

C. MEASURES OF EFFECTIVENESS (MOES)

The MOEs used in this research are the mission failure risk and the force protection risk. The measures of performance (MOP) associated with each MOE are shown in Table 10, along with the associated parameter from the simulation.⁵⁸ It is the MOP data that is analyzed to make inferences about the MOEs.

⁵⁸ **Measure of Effectiveness (MOE):** A qualitative or quantitative measure of the performance of a model or simulation or a characteristic that indicates the degree to which it performs the task or meets an operational objective or requirement under specified conditions.

Measure of Performance (MOP): Measure of how the system/individual performs its functions in a given environment (e.g., number of targets detected, reaction time, number of targets nominated, susceptibility of deception, task completion time). It is closely related to inherent parameters (physical and structural), but measures attributes of system behavior. Defense Modeling and Simulation Office Glossary, <https://www.dmsomil/public/resources/glossary/>. Last accessed on 11 August 2006.

MOE	MOP	Pythagoras Parameter
1. Mission Failure Risk	1.1 Area Coverage	% of red agents killed
2. Force Protection Risk	2.1 Impact on Personnel	% of patrols injured
	2.2 Cumulative Interactions	Average generic attribute level.

Table 10. Measures of Effectiveness and Measures of Performance

D. PARAMETER COMPARISON

This section looks at the effects critical parameters have on the outcome of the simulation. The comparisons are made from data from simulation runs of all three scenarios using the NOLH design outlined in Chapter III. Each scenario contends with 257 different combinations of red force composition. The 257 combinations are not specifically categorized into the 10 threat levels like the custom design. Instead, these different combinations of red forces are designed to test each blue force at a wide range of challenges; from a very low to a very high threat environment. From this wide range of challenges, important parameters that define the threat environment fall out and patterns are identified using recursive partitioning (also known as regression trees). Recursive partitioning is a technique used to identify the parameters that best predict the dependent variable of interest. Variations of recursive partitioning are referred to by many names, including decision trees, Classification and Regression Trees (CARTTM), Chi Square Automatic Interaction Detection (CHAIDTM), C4.5, C5, and others.⁵⁹ Regression trees are used when the dependent variable is continuous and classification trees are used when the dependent variable is categorical. Since the dependent variable in all cases is continuous, regression trees are used. More specifically, the trees are binary regression trees, where each parent node has only two child nodes. Each regression tree is grown to size 4 (four terminal nodes or leaves). All trees grown beyond size 4 reflected the parameters that had already appeared and therefore are not useful in providing insight into critical parameters. Therefore, four terminal nodes are used as the stopping condition for partitioning.

⁵⁹ SAS Institute, Inc., *JMP Statistics and Graphics Guide*, Version 5, Copyright 2002, p. 483.

E. PARAMETER COMPARISON FOR MISSION FAILURE RISK MOE

The regression tree shown in Figure 25 for the Division Scenario partitions the data set on the initial number of escalation agents. The value the partition is made on is escalation agents ≥ 10 and < 10 . The nodes for this split can be seen in tier 2 (depth 1) of the regression tree. The value of a partition (split) can be seen in the header of each box in the tree. The algorithm for the regression tree selects partitions on independent variables by fitting means and then selecting the split in the data that most significantly minimizes the sums of squares of the means for the two groups. It is taking the data set and grouping it into like observations, so as to minimize the sums of squares of the new subsets. Essentially, each successive split is determining the independent variable that has the greatest effect on the outcome of the dependent variable, much like a stepwise regression. Each box within the regression tree reflects the “count” or number of observations that is partitioned into that subset as well as its mean and standard deviation. The large plot above each tree graphically depicts all the observations along with each partition and the mean of the partitioned group (the mean is the solid black line in the scatter plot of Figure 25). The marginal data to the left of the scatter plot shows the percent of variation explained by the partitioning (R-squared) and the number of total observations (N). Here the total observations is 257, or the number of design points in the NOLH design.

The second and third split in the tree (tier 3) show the significance of Event10. The partition is between the values of 11 to 12 Event10 agents. This is no surprise because Event10 is the most severe of the events. It is the most resistant to being influenced as well as has the highest level of negative impact on the patrols. What is a surprise is that the number of escalation agents is the most significant in terms of mission failure risk. The relative importance of Escalation agents is much higher than the number of Event10 agents. This is evident by the vertical color bands in Figure 26. As the number of Escalation agents increase, the area coverage performance of blue decreases. This decrease is almost independent of the number of Event10 agents until it is above 12 agents. This is seen in the upper right corner of the contour plot in Figure 26.

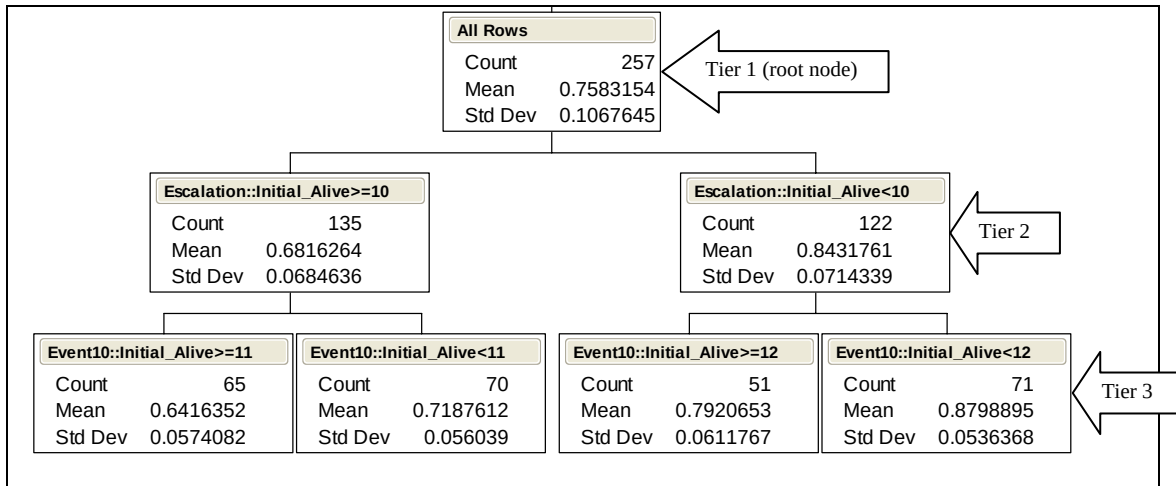


Figure 25. Division Scenario Regression Tree Showing Three Partitions of Data for % of Red Agents Killed (Area Coverage)

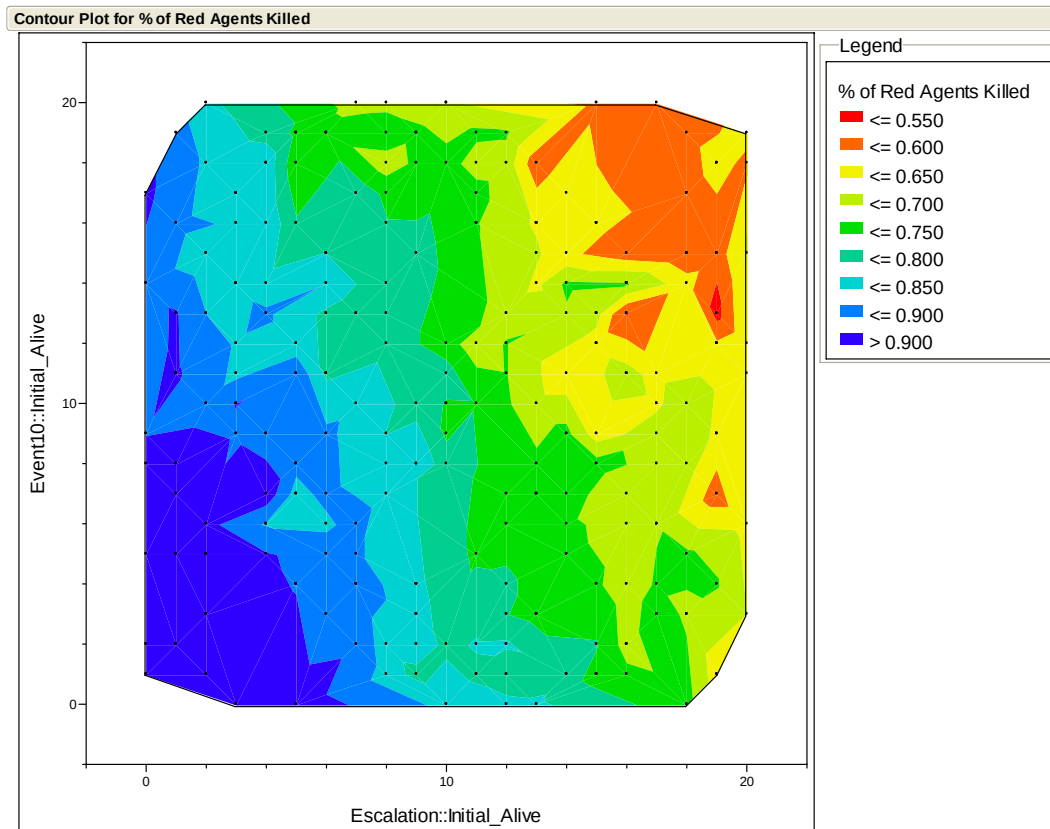


Figure 26. Division Scenario Contour Plot for % of Red Agents Killed (Area Coverage)

Next is a look at the regression tree for the Brigade and Brigade (-) Scenarios to see if the same parameters most affect the mission failure risk.

In the Brigade Scenario, like the Division Scenario, the number of escalation agents weighs the heaviest on the outcome of mission failure risk. This is shown by the first partition in the regression tree in Figure 27. The more Escalation agents, the higher the risk of mission failure. What is different from the Division Scenario is the importance of Insurgent agents outweighs the Event10 agents. However, the relative worth of the Insurgent agents is small in comparison to the Escalation agents. This can be seen by the vertical color bands in the contour plot in Figure 28. Like Figure 26, it shows the percent of red agents killed (or area coverage achieved) is dependent primarily on the number of Escalation agents. The number of Insurgent agents really does not have the effect on the level of area coverage achieved. Further, what is surprising is that the area coverage is actually lower with lower numbers of Insurgent agents. This is seen by the redness in the lower right corner of Figure 28. This is completely counterintuitive; however, it suggests that when the level of escalation (number of agents) is that high, the insurgents really do not have an impact on the area coverage achieved by the blue force. In addition, when there are more insurgents in the simulation, more need to be “influenced” to maintain the same level of overall proportion killed.

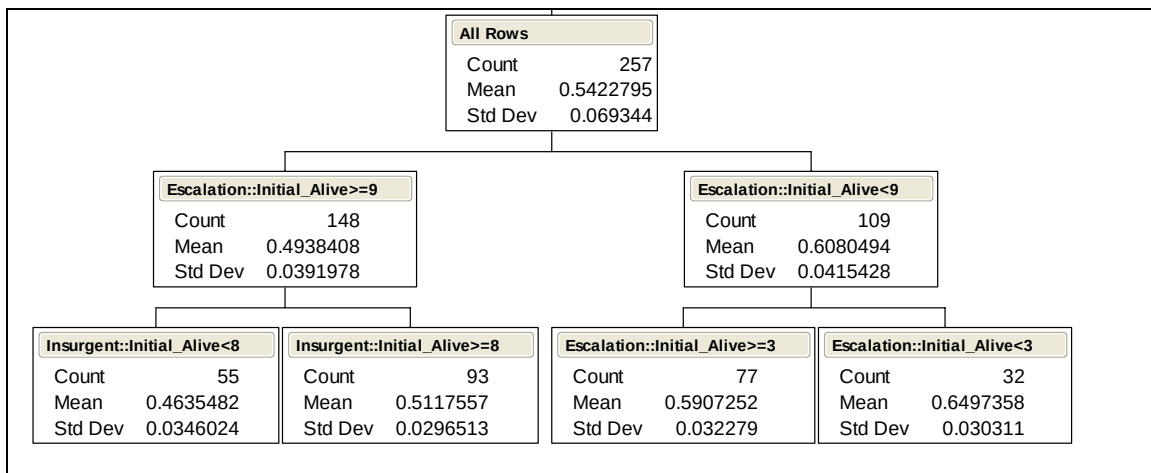


Figure 27. Brigade Scenario, Regression Tree Showing Three Partitions of Data for % of Red Agents Killed (Area Coverage)

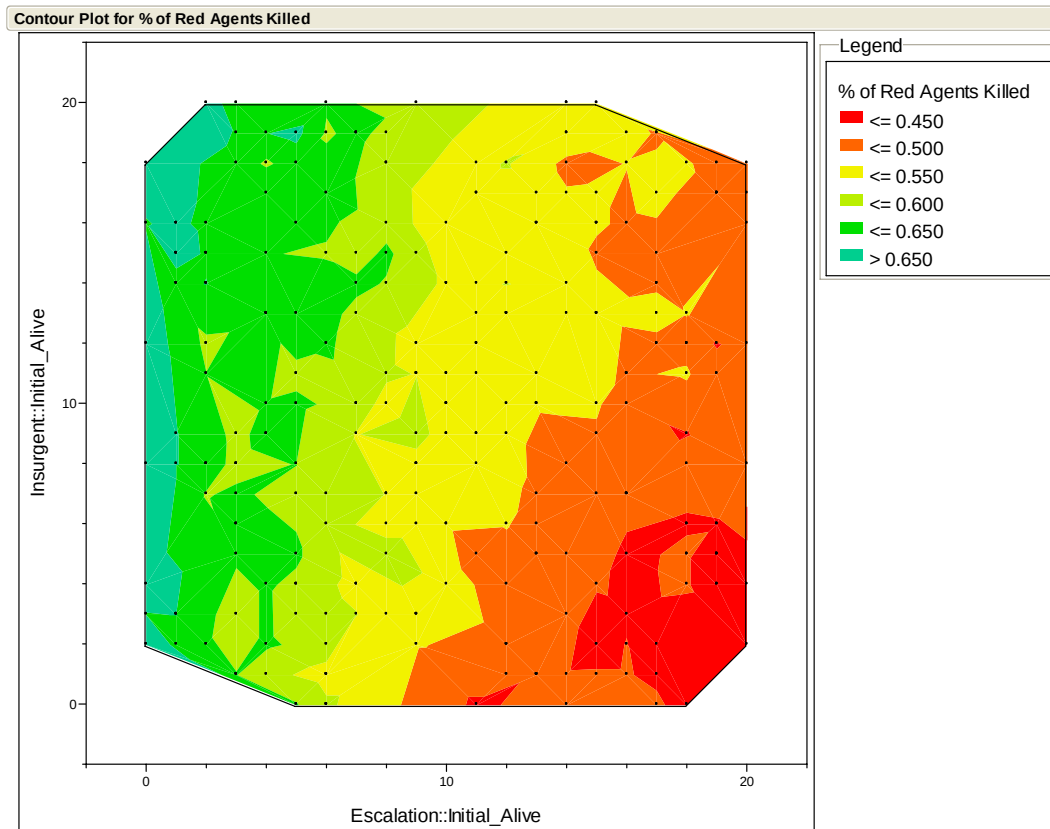


Figure 28. Brigade Scenario Contour Plot for % of Red Agents Killed (Area Coverage)

The Brigade (–) Scenario shows slightly different results than the Division and Brigade Scenarios. The number of Escalation agents is still crucial; however, the regression tree in Figure 29 shows that it is secondary to the number of Event10 agents. This is the opposite of the Division results. However, the relative importance of Event10 is not much more significant than the impact of Escalation on area coverage. This is seen in Figure 30, where the color bands are more diagonal than horizontal. Had the color bands been more horizontal it would suggest a much greater relative impact of Event10 over Escalation on the outcome of area coverage (mission success).

The reason Event10 agents are more significant than Escalation agents in the Brigade (–) Scenario is the blue forces are highly dispersed. The dispersion of blue forces in this scenario allowed them to maintain a near continuous presence. This has the effect of repelling escalation agents from reviving Event and Insurgent agents. The more consolidated the force, the greater the effect Escalation agents have at inflaming the

situation and causing instability. The Brigade (–) Scenario clearly demonstrates the importance of force disposition on the outcome of the simulation. The significance of this finding will be discussed further in Chapter V.

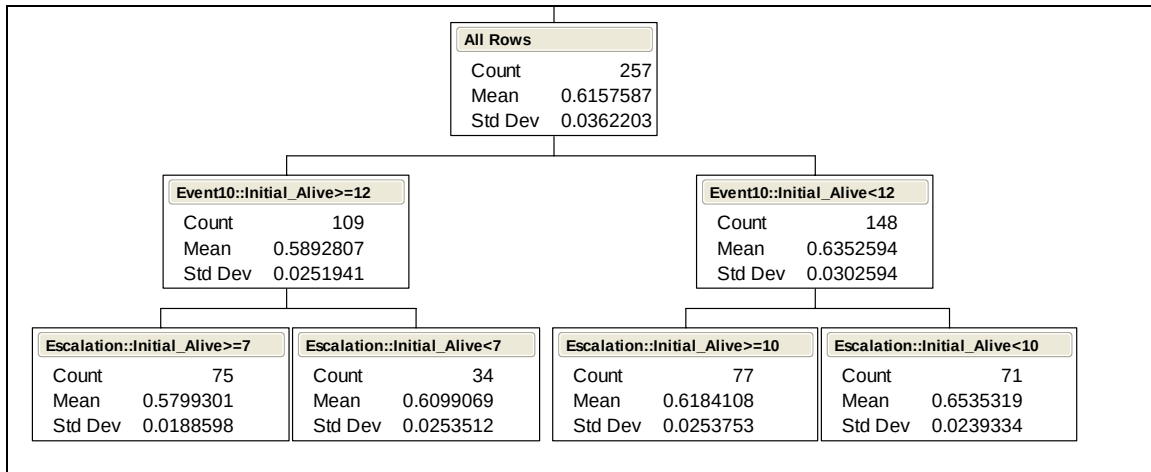


Figure 29. Brigade (–) Scenario Regression Tree Showing Three Partitions of Data for % of Red Agents Killed (Area Coverage)

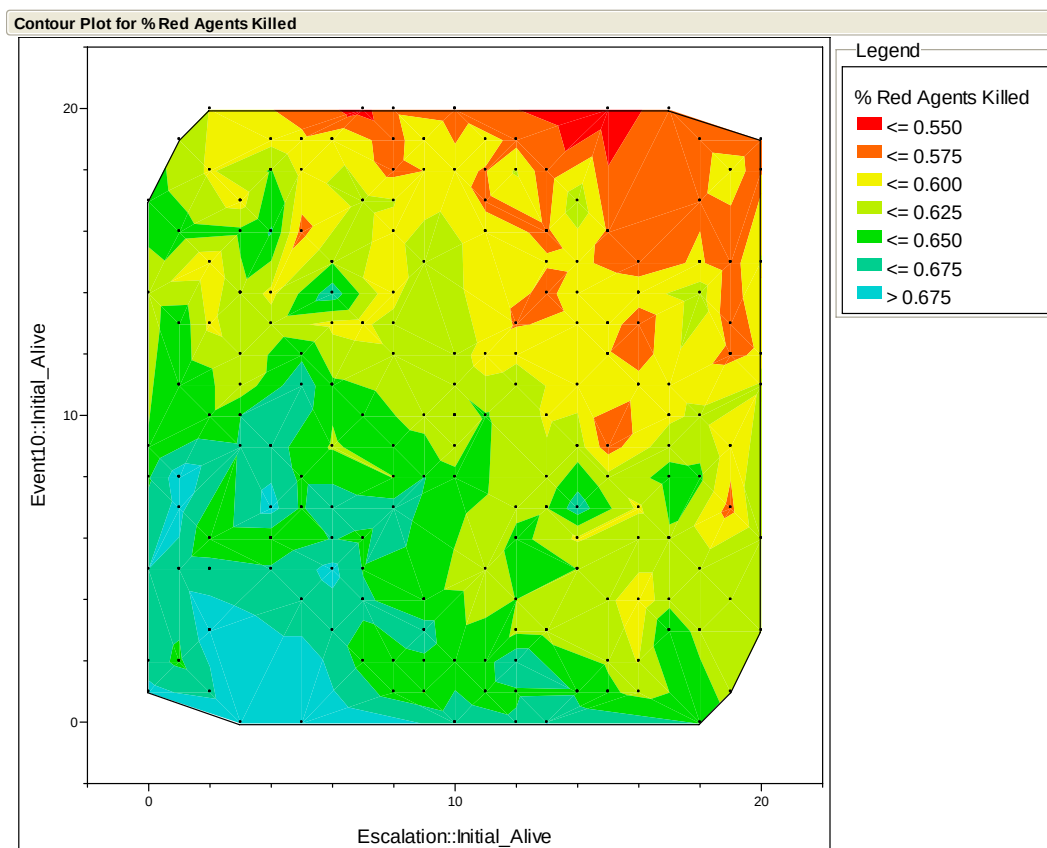


Figure 30. Brigade (–) Scenario Contour Plot for % of Red Agents Killed (Area Coverage)

In summary of the mission failure risk parameters, it is clear that escalation is the dominant variable in relation to mission failure risk. The Escalation agents within the simulation have a greater impact on blue's area coverage than any of the other parameters. The comparison of the three regression trees are shown in Table 11.

Scenario	1st Partition Parameter	2nd Partition Parameter
Division	Escalation	Level 10 Event
Brigade	Escalation	Insurgent
Brigade (-)	Level 10 Event	Escalation

Table 11. Comparison of Regression Trees in Terms of Mission Failure Risk

What is also apparent by these results is that the basing strategy of the three force sizes has a significant impact on the outcome. Although the Brigade (-) is the smallest of the forces, it is the most dispersed. Therefore, it is sensible that the Level 10 Events outweighed the Escalation agents in importance. The escalation agents are only active in the absence of blue forces and therefore didn't play as great a role as they did in the other two scenarios. The Brigade Scenario is the most consolidated of the three scenarios. As a result, it requires the most travel distance to/from in order to influence Event agents. This allowed more opportunity for Insurgent agents to engage patrols. It is the time wasted in these engagements that makes the Insurgent agents crucial to the area coverage success in the Brigade Scenario. The significance of the posturing of forces is discussed further in Chapter V.

F. PARAMETER COMPARISON FOR FORCE PROTECTION RISK MOE

Just like the analysis conducted for mission failure risk, the same process using regression trees is used to analyze force protection risk. Again the data is from simulations utilizing the NOLH design. Analysis of the Division Scenario (Figure 31), demonstrates that Event10, followed by Event9, are the most crucial factors in terms of force protection risk. Force protection risk in this tree is measured by the cumulative interaction MOP. In other words, it is the level of generic attribute that patrols accumulate through interaction with red agents. The contour plot of Event10 and Event9 in Figure 32 shows that both carry about the same level of significance. It also clearly shows that more of Event10 or Event9 agents are bad for the blue force.

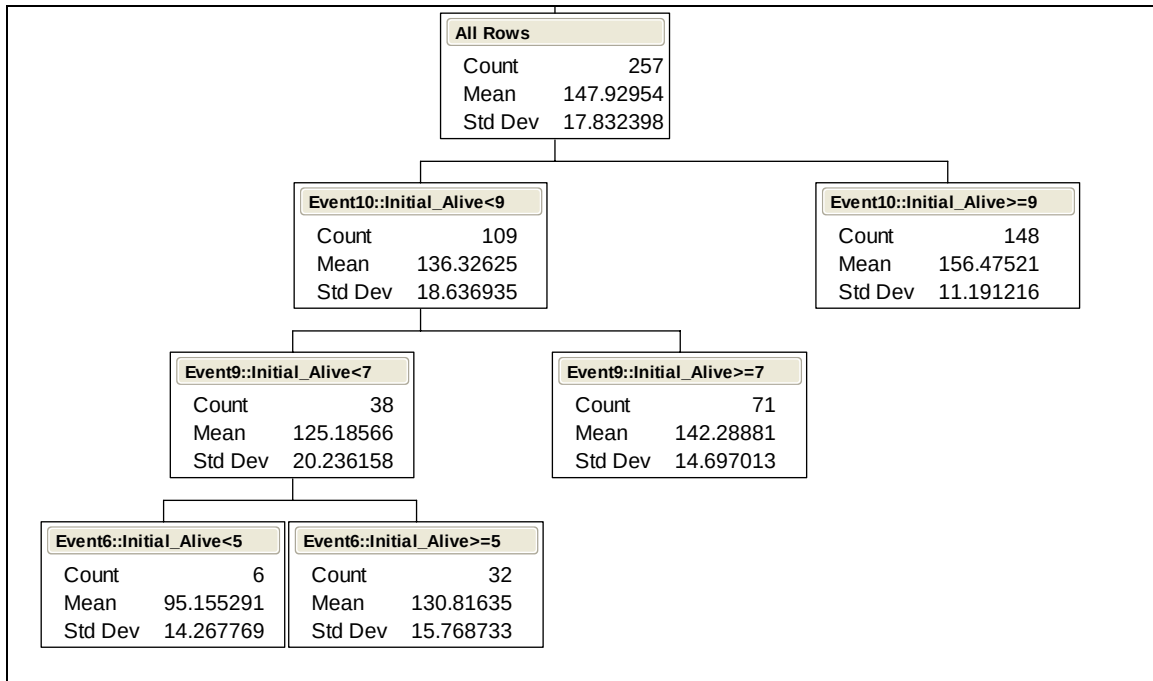


Figure 31. Division Scenario Regression Tree Showing Three Partitions of Data for Average Patrol Attribute (Force Protection Risk)

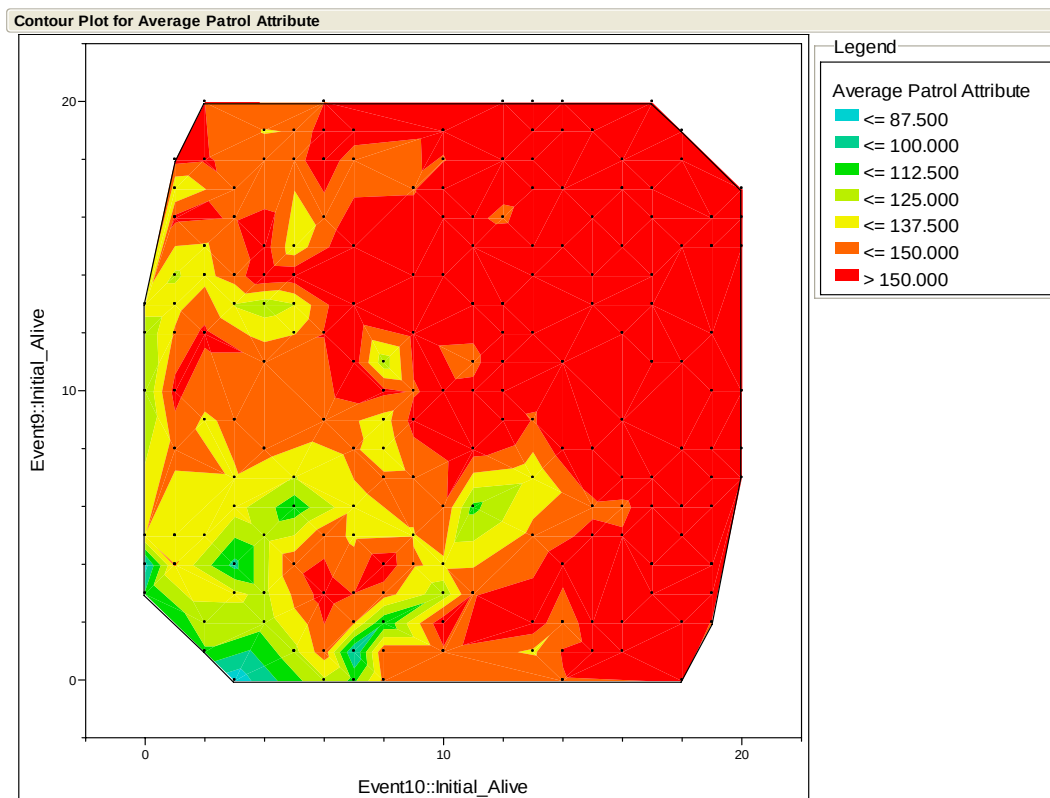


Figure 32. Division Scenario Contour Plot for Average Patrol Attribute (Force Protection Risk)

In the Brigade Scenario, it is the instance of Escalation agents that weighs the most on the force protection risk, as seen in Figure 33. The importance of Escalation agents is followed by the number of Event10 agents. However, the two parameters are roughly equal in importance, as shown by the approximate diagonal color bands in Figure 34. It is important to note that the choppiness in Figure 34 is due to the fact that there are many other factors being varied simultaneously. Thus, the reader should focus on broad trends in the color distribution.

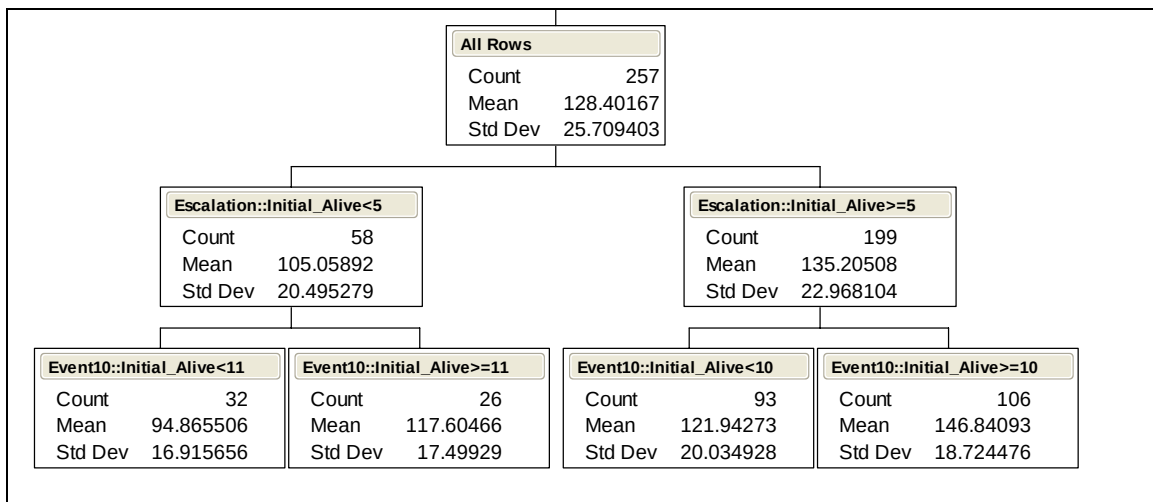


Figure 33. Brigade Scenario Regression Tree Showing Three Partitions of Data for Average Patrol Attribute (Force Protection Risk)

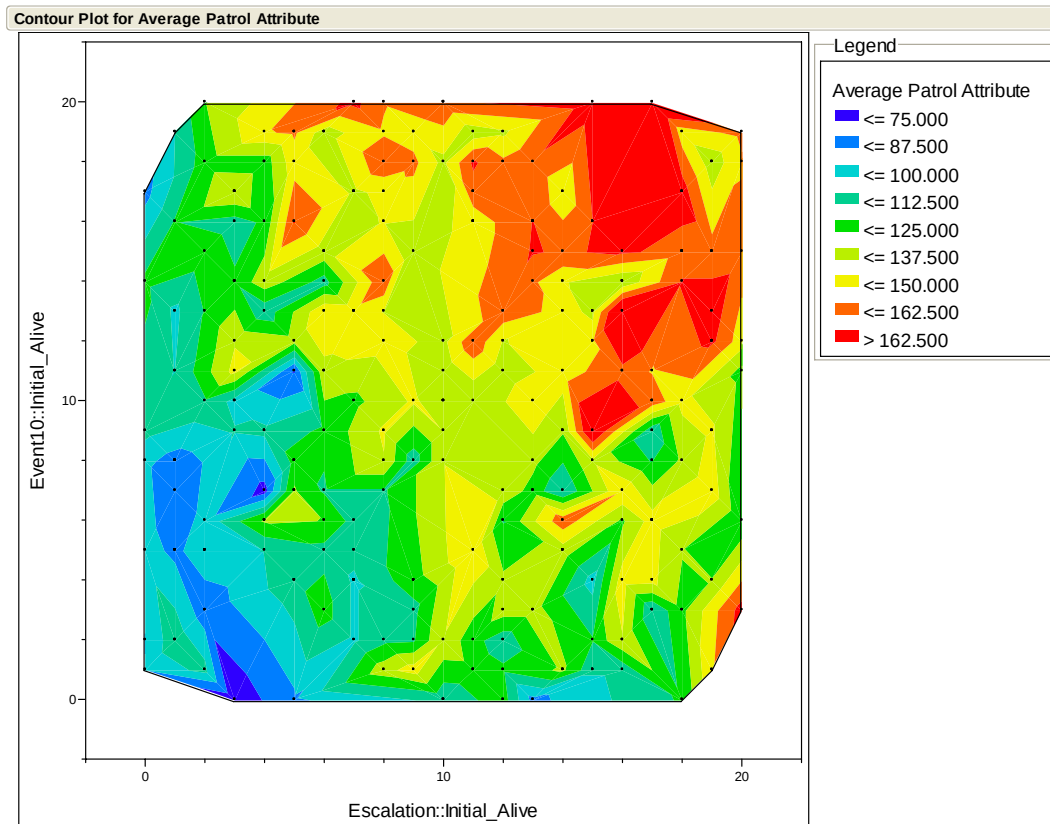


Figure 34. Brigade Scenario Contour Plot for Average Patrol Attribute (Force Protection Risk)

In the Brigade (–) Scenario, it is the instance of Insurgent agents that weighs the most on the force protection risk, as seen in Figure 35. The importance of Insurgent agents is followed by the number of Event10 agents. However, the two parameters are roughly equal in importance, as shown by the rough diagonal banding in the Figure 36 contour plot.

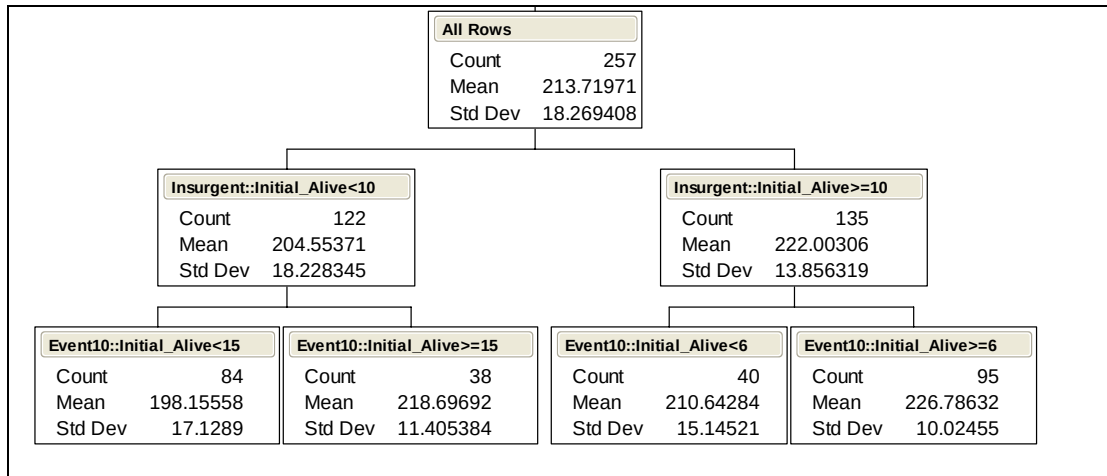


Figure 35. Brigade (-) Scenario Regression Tree Showing Three Partitions of Data for Average Patrol Attribute (Force Protection Risk)

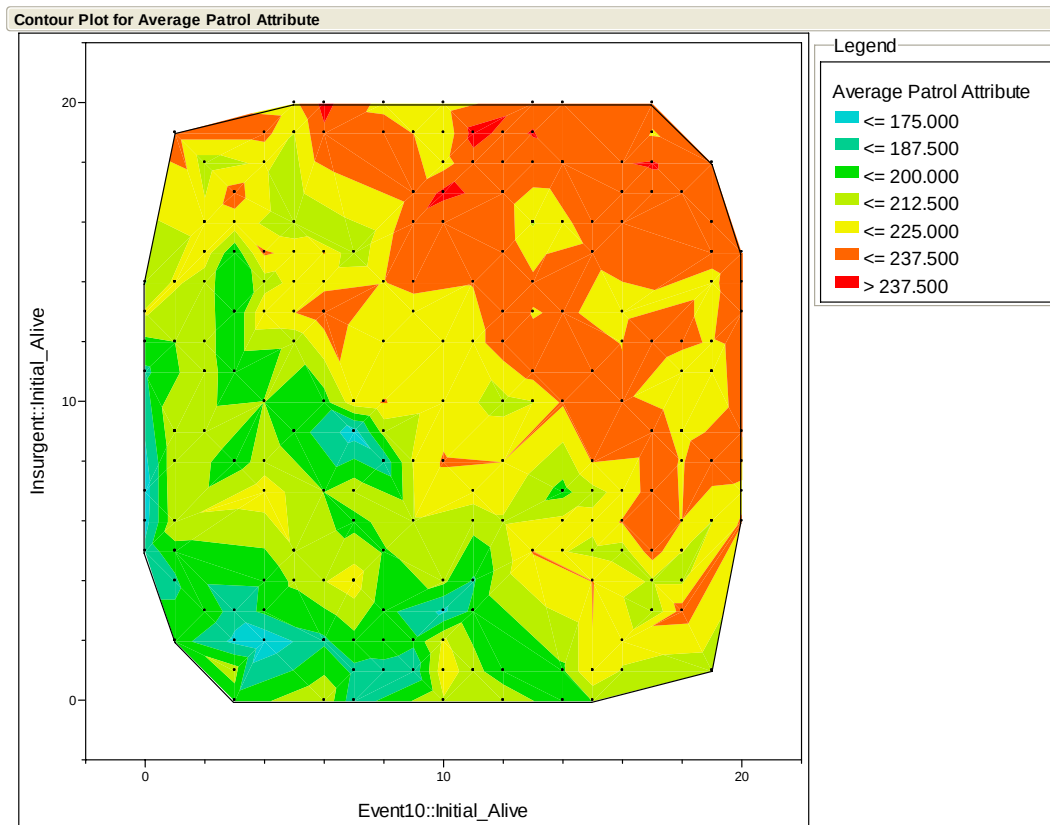


Figure 36. Brigade Scenario Contour Plot for Average Patrol Attribute (Force Protection Risk)

In summary of the force protection risk parameters, the number of Event10 agents is the most significant overall. It is intuitive that the level of force protection risk is most

dependent on the occurrences of the most severe event (Event10). This is seen most in the Division Scenario. Insurgents are not coming into play because of the duration of the simulation. The Insurgents are typically eliminated early on in the simulation because of their aggressiveness to disrupt blue operations. Once they are effectively influenced, their proximity (location in which they are killed) to blue forces does not allow them to be revived by the Escalation agents as often as the Event agents. The Events that are far away from blue garrisons are the most easily provoked (escalated) by the Escalation agents. This is due to the lack of continuous presence in the remote areas. Typically these events are influenced when a patrol responds and then become provoked by the escalation agent in the absence of a patrols presence.

In the Brigade Scenario, again the Escalation agents weigh the heaviest due to the consolidated nature of the forces. The consolidated posture provides an opportunity for Events to escalate due to the lack of presence by the PKF. When Events are allowed to become inflamed it poses a great force protection risk to the force.

In the Brigade (–) Scenario, Insurgents are the prevailing factor in affecting the force protection risk. Opposite form the Brigade Scenario, where the consolidation of forces makes the PKF vulnerable to Escalation, the dispersion of the Brigade (–) Scenario makes the PKF vulnerable to the Insurgent agents. Escalation and Insurgents do not affect the force protection risk to the Division because it is able to maintain both dispersion and overwhelming force. In addition, the Division force has the greatest number of QRFs that can quickly reinforce lone patrols threatened by an Insurgent. Table 12 summarizes the significant factors in each scenario that affect force protection risk.

Scenario	1st Partition Parameter	2nd Partition Parameter
Division	Level 10 Event	Level 9 Event
Brigade	Escalation	Level 10 Event
Brigade (–)	Insurgent	Level 10 Event

Table 12. Comparison of Regression Trees in Terms of Force Protection Risk (Attribute Level)

The other MOP used for force protection risk is the average number of injured patrols at the end of a simulation run. Although this MOP does give some insight into

force protection risk, it is not as useful because every time a patrol returns to base its health is fully restored (i.e., it is no longer injured). Therefore, the average injured patrols MOP is just a snapshot in time, whereas the cumulative attribute level MOP accounts for interactions throughout the entire duration of the simulation. The analysis of parameters impacting the percent of injured patrols is included in Appendix C. Analysis of the data from the custom design is discussed in the following section.

G. COMPARISON OF MISSION FAILURE RISK USING CUSTOM DESIGN

Each simulation recorded the number of red agents that were influenced (killed) at the end of the simulation run. Like the NOLH design, the percent of red agents killed is used as the measure for area coverage (or level of presence) achieved by blue patrols. However, the measure for mission failure risk is simply one minus the area coverage (1-AC). As the area coverage decreases, the risk of failing the mission increases. Although most of the following discussion refers to area coverage and mission success, it should be understood as a surrogate for the mission failure risk MOE. The goal of the PKF is force projection in order to achieve the security necessary for stability to take hold. If force projection or area coverage is not achieved, the PKF is considered to be failing the mission. There is not a specific level of area coverage that defines success or failure. It is a measurement that is the discretion of the commander. In some operations, success will be defined as greater than 90% coverage, in others greater than 50% is adequate—i.e., it is situational dependent. Whatever the level of success/failure is determined to be, the fact remains the same that less area coverage achieved increases the risk of mission failure.

The level of area coverage for all 10 threat levels is shown in Figure 37, which shows five colored lines for each force level (Division, Brigade, Brigade (-)). Each line reflects the results of 2-, 4-, 6-, 8- and 10-day simulation durations. As was expected, each plot shows a greater level of area coverage at the lower threat levels and falls off toward the higher threat levels. In addition, each force achieves greater area coverage as time progresses from 2 to 10 days. The rate of increased area coverage diminishes for each force as time progressed. This is seen by the large space between a day 2 plot and day 4 plot. In comparison, the space between the day 8 and day 10 plot is a much smaller distance.

What is a surprise is that the Brigade (-) force overtakes the Brigade force in its level of area coverage. This occurs around day 5. Looking from the bottom up, the order of success for 2 days is Brigade (-), Brigade, Division (or green, red, blue). This is the same order for the 4-day plots. However, the order for the 6- , 8- , and 10-day plots changes. The new order of success (lowest to highest) is Brigade, Brigade (-), Division (or red, green, blue). A smaller force achieving a greater amount of area coverage than a larger force is counterintuitive. This is because the disposition of forces in the Brigade versus the Brigade (-) Scenario. As previously discussed, the consolidated nature of the Brigade Scenario put it at a distinct disadvantage over the dispersed posture of the Brigade (-) forces.

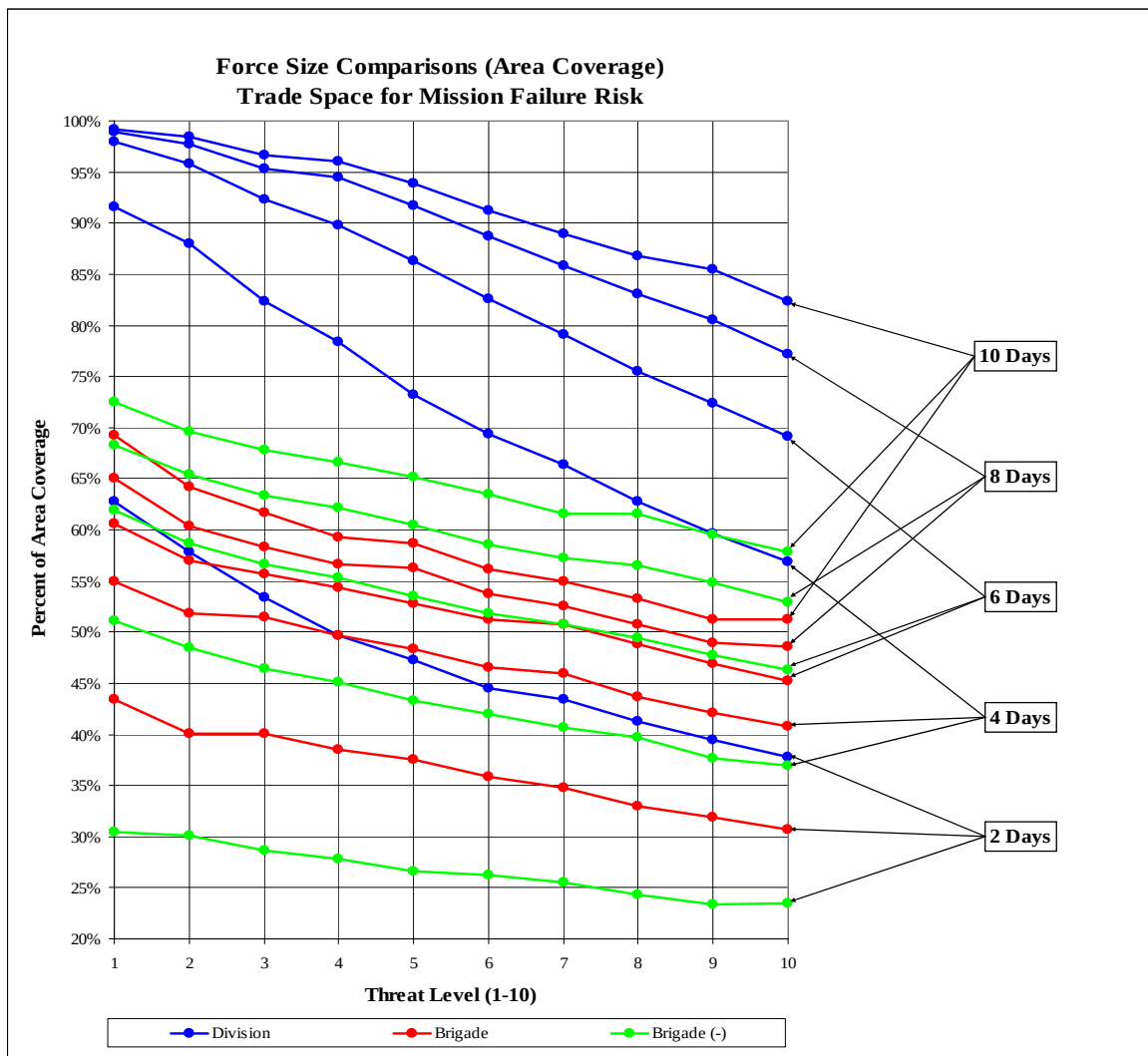


Figure 37. Comparison of Area Coverage (Mission Success) of All Force Levels Over a 10-Day Period (Best viewed in color)

1. Time Comparison

Before the discussion of trade-space it is important to put the measure of time into context. The simulations were run for 2- , 4- , 6- , 8- , and 10-day durations. This is based on defining a time step as 2½ minutes. However, the operational tempo within the simulation is highly accelerated. Time-step models prohibit simulation durations of months or years, which are better time continuums for Stability Operations than days. Therefore, the activity put into the simulation is meant to represent a much longer duration in a real world stability operation. The 100 incidents occurring in the simulation are representative of approximately 3 to 6 months of operations in Bosnia.⁶⁰ In the Somalia operation in 1992, 100 incidents would have occurred in approximately 8 to 10 months, or roughly a reportable incident every three days.⁶¹ Therefore, in the simulation, the assumption is loosely made that a day is an approximate representation of a month. The important concept to understand is that when referring to trade-space, it is a proportional relationship. For example, if a Division achieves a desired level of success in 2 days in a situation that takes a Brigade 6 days, it is a 3/1 ratio. Therefore, however, time is defined the proportional ratios remain the same.

2. Identifying Trade-Space in Terms of Mission Failure Risk

Figure 37 can be used as a tool for analysts in identifying the trade-space of a smaller force achieving a relative level of mission success of a larger force. An example of the trade-space on Figure 37 is where two line plots intersect (or come close to one another). For example, at threat level 9, a Division force can achieve approximately 60% area coverage in a 4-day period. The Brigade (–) force achieves the same level of 60% area coverage in a 10-day period. This is an identifiable trade-space at threat level 9. The proportional ratio of the trade space is 10/4 units of time. In other words, a decision to downsize assumes that it will take 2½ times longer to achieve parity in the desired level of area coverage. Besides time, the other consideration in trade-space is the force protection risk. This is discussed in Section H.

⁶⁰ Estimated by counting the number of major new incidents reported by the UN International Police Task Force (IPTF) weekly report in Bosnia. Major new incidents reported for week ending 10/5/2000 was six, week ending 11/10/2000 was five, week ending 12/1/2000 was five. http://tfe-ace.dcsint.hqusareur.army.smil.mil/archieves/sitreps/ipdf/doboj/2000010/001008_doboj.html. Last accessed on 21 August 2006.

⁶¹ Col Edward Lesnowicz, USMC (Ret.), Battalion Commander during Operation Restore Hope, Somalia, 1992, Interview with author, 12 August 2006.

Assume that trading an extra six days of time to downsize to a smaller force (2½ time factor) is acceptable to a commander. If it is believed that the threat environment will continue to improve over time, than the actual time to achieve a 60% area coverage will be less than the estimated six days. As the threat diminishes the threat level might drop to between 5 and 6. In this case, the Brigade (–) can achieve an area coverage of 60% in approximately eight days. In this case, the trade-space ratio is 8/4, meaning it will take twice as long to achieve parity in area coverage with the smaller force.

Figure 37 does not imply that once 100% area coverage is achieved the mission is successful and the troops can redeploy home. It is only a measure of what coverage is acceptable to the commander. A force could achieve a high level of area coverage in an operation that continues for years. This was the case in Bosnia and Kosovo. Ultimately, mission success or mission failure will be determined by many factors and not judged solely on area coverage. This is but one metric of many for mission success.

Ideally, the simulations for the Brigade and Brigade (–) Scenario should be run for durations that achieve parity with the Division 10-day simulation. In other words, extend the duration of all simulations until they achieve a near 100% area coverage at threat level 1. By doing this, the graph would provide greater fidelity at identifying the trade-space between force levels.

H. COMPARISON OF FORCE PROTECTION RISK USING THE CUSTOM DESIGN

Like the tool for identifying trade-space in mission failure risk, Figure 38 and 39 can be used to identify the trade-space relative to force protection risk. As previously described, two MOPs were used in determining the risk to a force. The better of the two measures is the count of Patrol Agent generic attributes, which accounts for the negative interactions for the duration of the simulation. The results utilizing this MOP are seen in Figure 38. In this graph, it is evident that as the threat level increases, the level of patrol attribute accumulation increases. This is exactly what is to be expected in this MOP. However, it was not expected that the Division-sized force would be at a higher level of force protection risk than the Brigade, at least in terms of patrol attribute level. Again, this is a result of the consolidated posture of the Brigade force. Because the Brigade requires more time to travel to and from events, it is not engaged as often and therefore

the patrols do not accumulate as much attribute. Because the Brigade patrols are not engaged as often, the area coverage achieved was lower than the other two forces as seen in Figure 37.

To demonstrate an example of force protection risk trade-space, the following example continues with the previous example used for mission failure risk. Looking at Figure 38, at threat level 9, after 4 days, a Division force has an average attribute level of 123. If downsized to a Brigade (–) it will take 10 days to achieve what the Division achieved in 4 days. Because of the added time necessary for the Brigade (–) to achieve the 60% area coverage the attribute level increases to 217 at the 10-day mark. Again, the attribute level is a measure of the total duration of all engagements patrols have with red agents. The more engagements (interactions with red) a patrol has, the more likely the patrol will suffer a casualty. If the relationship is linear, the ratio of force protection risk in this example is $217/123 = 1.76$. In other words, the smaller force is almost twice as likely to suffer a casualty (or 1.76 times greater force protection risk).

As this example has shown, the two areas of trade-space are not directly correlated. Identifying trade-space in mission failure risk does not synchronize directly with the trade-space in force protection risk. It has been shown that the trade-space in mission failure risk results in an increase in force protection risk to the smaller force. The two measures should be used in unison to find a balance acceptable to a commander in mission failure risk and force protection risk. Depending on the priorities of the commander, the importance of the two MOEs might shift and therefore the identifiable trade-space will change.

If force protection risk is the greater concern to the commander, an analyst can start with the force protection risk graph to identify trade-space and then move to the mission failure risk graph. An example of identifying trade-space from Figure 38. Assume a commander wants to down size a force from a Division to a Brigade and would like an estimate for the relative risk in terms of force protection that the smaller force will be exposed to. It is determined the threat level is 7 and after 4 days the Division accrues an attribute level of 112. The Brigade will accrue an attribute level of 112 around day 10. With this trade-space in force protection risk, an analyst would then compare the area

coverage the Brigade achieves in 10 days to that of what a Division achieves in 4 days. Again, Figures 37 and 38 need to be used together in accordance with the commander's priorities to identify the trade-space.

The actual data used in Figure 37, 38, and 39 can be found in Appendix D.

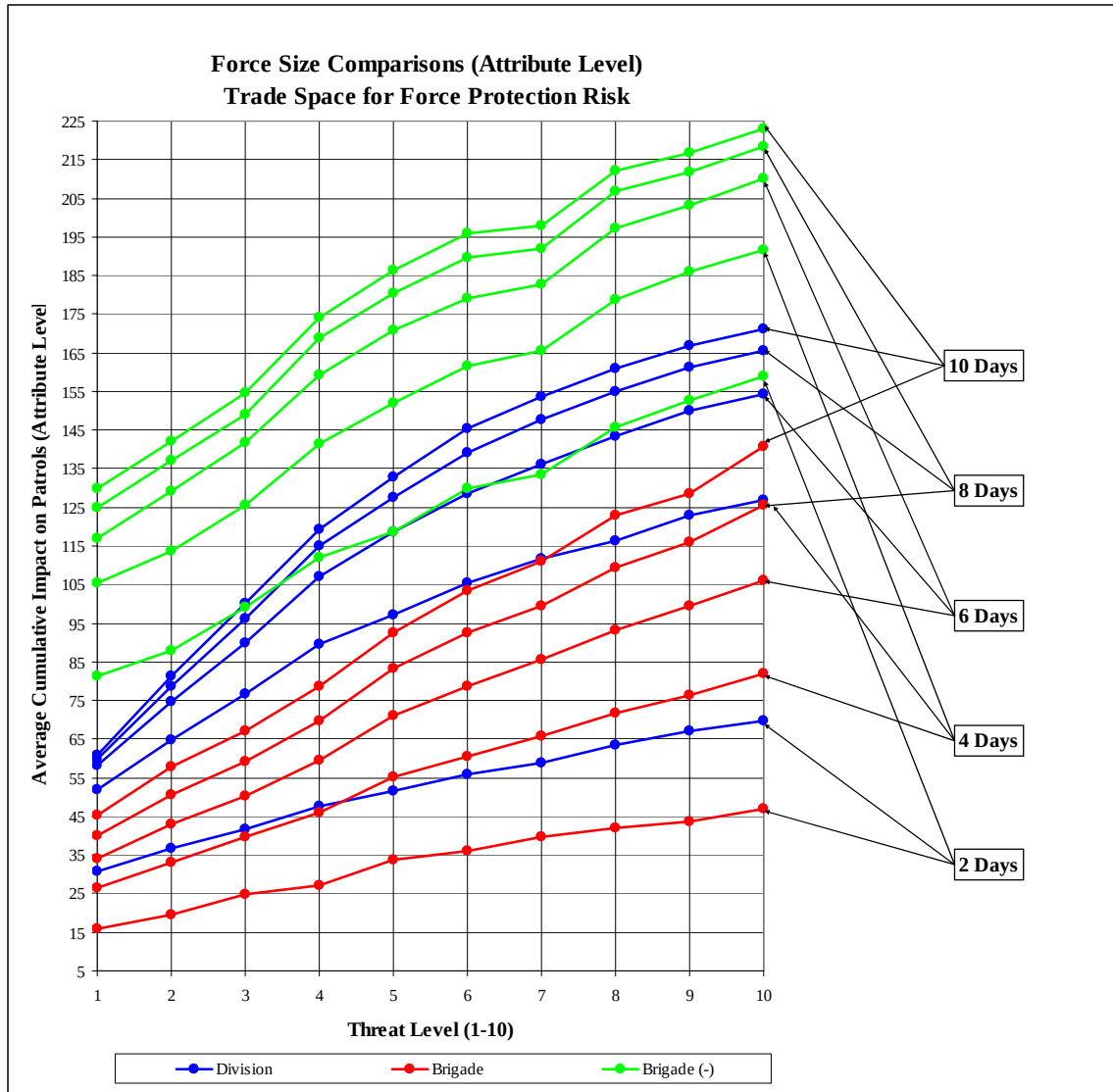


Figure 38. Force Protection Risk Comparison; Based on Force Size and Measured by Patrol Attribute Level

The lesser MOP for force protection risk is shown in Figure 39. Just like the graph in Figure 38, it is a measure of force protection risk, in terms of the number of patrols injured at the end of a simulation. Again, “injured” refers to a negative impact on

a patrol as a result of conducting their missions. It does not necessarily mean a casualty has occurred. It does imply that the higher the number of patrols negatively impacted, the greater the risk the PKF is to sustaining casualties. The graph shows that the longer the duration (from 2 to 10 days), the more patrols will risk injury. The plots are surprisingly flat, meaning that the level of “injured” patrols is very similar at threat level 1 as threat level 10. This is especially the case with the Brigade (–) PKF. This is due to the fact that the response variable for this measurement is binary, meaning a patrol is either at 100% health (Not Injured) or less than 100% (Injured). Currently, Pythagoras does not record the level of final health, so there is no way to determine how injured a patrol is. Therefore, if a patrol is out conducting a mission it is likely to be “injured” in terms of the simulation. The fidelity of the attribute accumulation in Figure 38 makes it a better gage of force protection risk than the “injured” patrols represented in Figure 39. However, Figure 39 is more intuitive in the sense that the smaller forces are represented at higher force protection risk. This is because the data in Figure 39 accounts more for the physical size of the force and its ability to protect itself. A big part of this is the number of QRFs available and their time to respond. In addition, attribute level (Figure 38) is more sensitive to the force disposition than the “injured” patrols measure is (Figure 39).

Continuing with the example of trade-space previously used, an analyst can cross validate estimates of force protection risk from Figure 38 with Figure 39. In Figure 39, at threat level 7 a Division is at 10% injured patrols after 4 days. By comparison, a Brigade is at 32% injured patrols after a 10-day period. In terms of ratio, if the risk is linear over time, the Brigade is at roughly three times ($32/10 = 3.2$) the force protection risk as the Division.

Now, referring back to the example used in identifying trade-space for mission failure risk (Section G), a Division achieves a 60% area coverage at 4 days, which takes the Brigade (–) 10 days in threat level 9. This information can then be applied to Figure 39 to show that at 4 days the division is at 12% force protection risk and at 10 days the Brigade (–) is at about 68% force protection risk. This translates to an estimate that suggests the Brigade (–) force protection risk is roughly $5\frac{1}{2}$ times greater

(68/12 = 5.6). Although the area coverage achieved in the downsizing is attractive, a commander has to weigh the tolerance for assuming a greater force protection risk with the smaller force.

To reemphasize the point, the trade-space for mission failure risk and force protection risk are not synchronized, but they are correlated. Both measures should be used collectively to find the balance according to the commander's priorities.

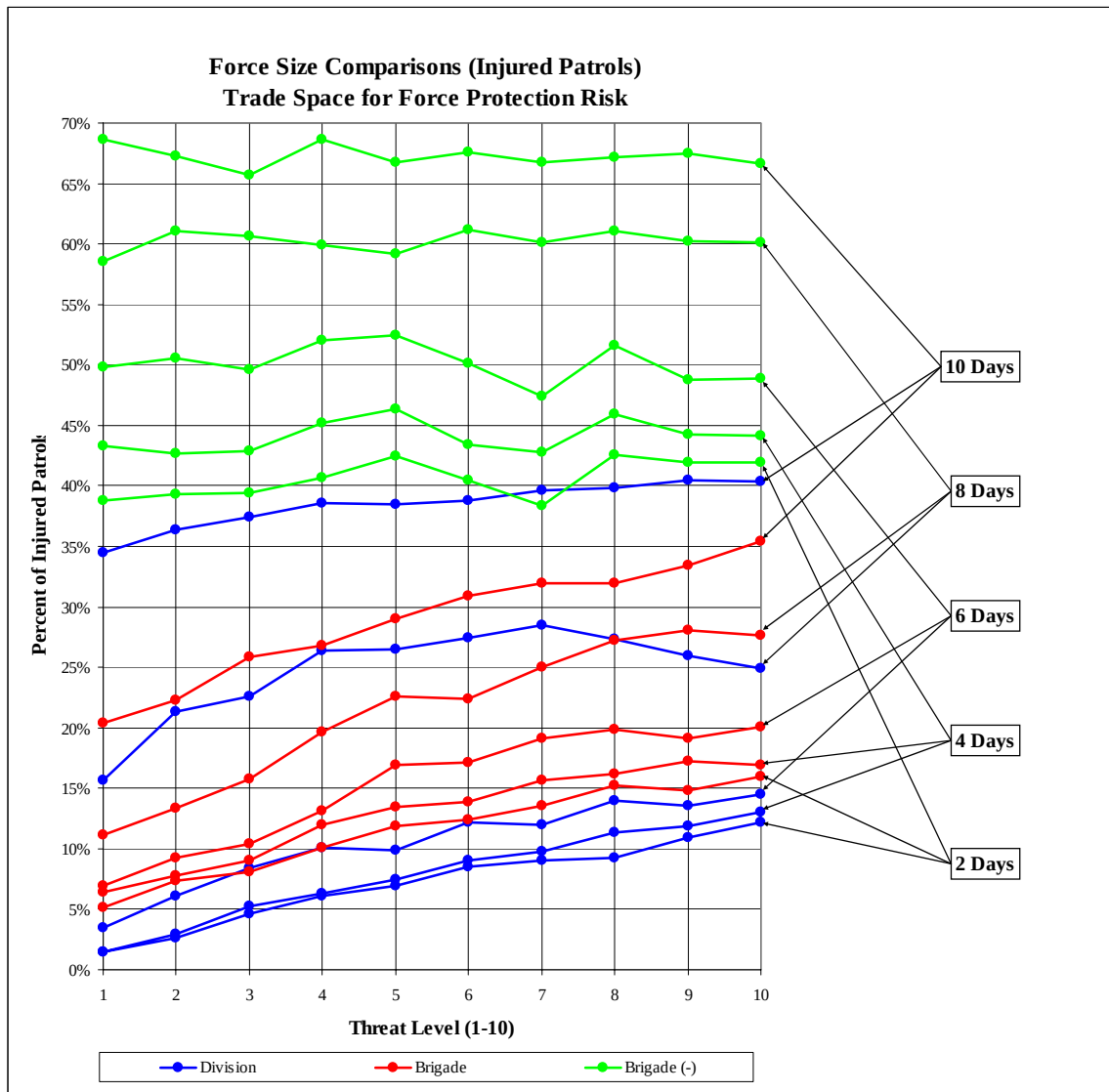


Figure 39. Force Protection Risk Comparison; Based on Force Size and Measured by Percentage of Injured Patrols

I. CHAPTER SUMMARY

This chapter presented the analysis of the data from the simulations. The analysis of the NOLH design demonstrated the overwhelming importance of escalation in model. The translation of this importance to the real world is discussed in the following chapter. In addition, Chapter V continues the discussion of identifying trade-space in the two critical areas of mission failure risk and force protection risk. Chapter V also expands on the insights drawn from the data analysis and draws conclusions. Chapter VI follows with recommendations for further research.

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V. INSIGHTS AND CONCLUSIONS

There are no finite answers to many questions. What really counts is your thought process. That process helps you get closer to the darker shade of grey. There are rarely black and white answers.

–Jack Welch
CEO, General Electric
1980-2001

A. INTRODUCTION

This chapter expands on the statistical analysis presented in Chapter IV. Chapter V is more of a discussion of the statistics, rather than a continuation of the analytical results.

It is important here to reiterate the old adage that “all models are wrong, but some are useful.”⁶² No model can perfectly simulate the real world. Instead, the intent is to develop simplified representations of the real world that behave in manners that are practical and realistic. This is the intent of the model used in this research. Once a simplified representation was built, the simulation was explored by varying the parameters (within a viable range of possibilities within the real world). This process of exploring the range of possible complex interactions and outcomes provided the data analyzed in Chapter IV. Here, the data are expanded on to gain insight into the questions. Namely, the considerations of risk of mission failure, force protection risk, and time all in relation to downsizing a force.

The term “gain insight” is used over and over in again in M&S. This is to instill realistic expectations on the part of decision makers on the contribution of modeling and simulation. Even if all the parameters and assumptions in a model are perfectly correct it will not be able to “predict” real-world outcomes. The real world is far too complex to use words like “predict” from a computer simulation. A more accurate way of stating the contribution of M&S is with words like “forecast” or “provide insight.” Some of the best analysts gave predictions on the numbers of casualties Coalition forces would experience in the first Gulf War through M&S. Most of the predications were off by more than a factor of 10. Although the M&S efforts were not great at predication, they were

⁶² Quote from George E.P. Box, http://en.wikiquote.org/wiki/George_E._P._Box. Last accessed on 21 August 2006.

invaluable at providing insight to decision makers on key issues. The following paragraphs present insight on the key issues of downsizing a force in a stability operation.

B. INSIGHTS AND CONCLUSIONS

Although analysts often use the phrase, “the model says this . . . ,” the truth is a model will never give a decision maker the answer. The insights presented in this chapter are not the answers to the problem. It is an analysis of the issues that should be considered by a decision maker based on simulation results. This research provides a vehicle to assist in that analysis.

1. Simulation Duration

Although the scenarios are compared across a duration of 10 days, the operational tempo is highly accelerated. The 100 events occurring in the 10-day scenario are representative of approximately 10 months. As discussed in Chapter IV, Section G.1, the assumption is made that one day of simulation time is roughly equivalent to one month of operational time. Regardless of what the operational tempo (frequency of events) is determined to be, the proportions of time identified as trade space in Chapter IV remain the same. For example, if it takes a Brigade 8 units of time (8 days in the simulation) to achieve a certain measure, which only takes a Division 2 units of time (2 days in the simulation), the 4/1 ratio is the same regardless of how much time a simulation day represents.

The limitations of time-step models required 10 months of events to be compacted into a 10-day simulation period. In time-step models, to ensure that important events are not missed, each time-step must be defined as a relatively short duration of real-world time. In these scenarios, a time-step represented 2½ minutes of real-world time. Any greater time than this results in erratic agent behavior. A 2½-minute time-step duration running for 100 days requires 57,600 time-steps. This is a ten-fold increase in model run time without any significant benefit to the model. Therefore, to create alternate scenarios to model, the analyst has to define the expected activity level or operational tempo. In other words, define the real-world timeframe of the simulated period in the model.

2. Presence

Although a comparison of basing strategies is not an intended goal of this research, it is apparent that it is the most significant factor in achieving presence in a

Stability Operation. Therefore, an important conclusion to deduce from the simulation is the significance of troop posture on force size transitions. This is evident by the results of the three scenarios starting with a dispersed Division, downsized to a consolidated Brigade, downsized further to a dispersed Brigade (-). Figure 11 in Chapter IV clearly shows the improvement in force presence the Brigade (-) achieved over the larger Brigade force. This is a direct result of a more dispersed garrison posture. Much like the Combined Action Platoons⁶³ in Vietnam, the Brigade (-) Scenario utilized small units dispersed throughout the U.S. sector effecting a quantifiable presence over the Brigade force that is consolidated on three camps. The lesson here is that presence matters and the best way to achieve presence is through dispersion. The simulations demonstrated that dispersion can have an even greater impact on the presence projection than the size of the force. However, the increase in area coverage (presence) is typically at a greater force protection risk. This is seen by comparing Figure 37, Mission Failure Risk with Figures 38 and 39, Force Protection Risk.

The trade-space plot for mission failure risk (Figure 37) seen in Chapter IV suggests that downsizing from a Division should skip the Brigade level and downsize directly to the Brigade (-). This is obviously an incorrect conclusion to draw from the research. This outcome is a direct result of the different distribution of the forces between the different scenarios. A correct conclusion to draw is not to skip force size transitions, but consider how to use a smaller force, in a more dispersed manner, in order to project presence. The importance of basing strategy as a parameter is evident; however, it requires more research to quantify troop dispersion to presence generated. Without specifically quantifying the values, this research demonstrates the value of dispersion at achieving presence.

The trade-space graphs in Chapter IV (Figures 37, 38, and 39) are highly dependent on the posture of forces. However, this dependency does not detract from the utility of the simple process of constructing the trade-space graphs from simulation data. In fact, the graphs and the three modeled scenarios mimic the force distributions from Bosnia, and therefore, it is possible that future Stability Operations could follow a similar

⁶³ Combined Action Platoons were small units, usually a squad, permanently assigned to individual villages in Vietnam. http://en.wikipedia.org/wiki/Combined_action_program. Last accessed on 18 August 2006.

pattern of downsizing (dispersion-consolidation-dispersion). Thus, this research highlights the effects of sacrificing dispersion (presence) as well as fewer numbers of troops. With a smaller force, the manner in which those forces operate (troop employment) and where they operate from (troop posture) become all the more critical to mission success.

When downsizing, the focus should be on how much presence can be maintained. Numbers of troops is obviously a big part of that, but must be considered in conjunction with the posturing and employment of those troops. A key question to ask is, “Is it possible to downsize a force and posture them in such a way so as to maintain parity in presence (area coverage)?” The decision of how the troops will be postured is just as important as how many troops to maintain. The common operational reaction is to consolidate as forces and bases are rolled back, just like in combat operations. However, the military mindset of Combat Operations has to be separated from Stability Operations. It was a bold decision in Bosnia to disperse the PKF by utilizing the base-houses. However, this decision only came about out of necessity rather than a conscious decision to project greater presence. This dispersion of the base-houses had surprising success in the simulation and should be studied further for consideration in future Stability Operations.

The other factor that is often overlooked is troop employment. In terms of the simulation, this is referring to the size and composition of the patrols. In most cases, the commander will set the SOP for patrol composition based on the threat level. The commander makes this decision in the context of the force protection risk. However, if the patrol size and composition decision is made more in the context of presence achieved, potentially more patrols could be generated and effect a greater presence.

3. Escalation

Much of the results in Chapter IV indicate the overwhelming significance that escalation plays in the simulation in terms of the amount of presence each force is able to achieve (see Table 11, Chapter IV). This raises the question, “If escalation is such an important parameter, how is it quantified?” An example of how an analyst could do this follows.

In the regression tree for the Division Scenario, the split was made at 10, which is the middle point of the range of escalation from 0 to 20. In this tree, the baseline level of area coverage is 75% across all threat levels (mean area coverage at root node). If 75% area coverage in presence is the goal of the commander, an analyst measures and estimates the escalation in the operational environment. If the escalation is above the 50% threshold on a theoretical scale (10 on a 0 to 20 scale), an analyst could deduce that the 75% area coverage will not be achieved and therefore more forces are required. If there is a high level of confidence that the escalation level is well below the 50% threshold, then the analyst can make the conclusion that the 75% area coverage will be achieved and the possibility of downsizing the force should be considered. The same methodology can be applied to different force levels and for different area coverage goals.

The simulation results, however, do not alleviate the problem of measuring and estimating the level of escalation within the operational environment. Just like trying to measure the threat environment, measuring the rate of escalation will continue to be a challenge for future operations.

Escalation appeared in the force protection risk MOE, but not to the same degree as it did in the mission failure risk (see Table 12, Chapter IV). In the measure of force protection risk, the severe events that inflicted a toll on the patrols overshadowed the escalation. However, in the Brigade Scenario, Escalation was the most significant force protection risk factor. This is because the consolidated nature of the Brigade gave the escalation time to take affect. This further supports the concept discussed earlier. Force posture, or in this case lack of presence, can result in a higher mission failure risk and a higher force protection risk. In both the Division and Brigade (–) Scenarios, the PKF was able to achieve a seemingly omnipresence, which negated the effect of escalation. Again, this is because the escalation only occurred during a lack of blue patrol presence. The Division achieved its presence through sheer numbers that saturated the sector. The Brigade (–) achieved presence though effective dispersion in the base-houses. The consolidated Brigade was unable to do either.

4. Insurgents

As modeled, Insurgents are seemingly ineffective with the larger forces. However, at the Brigade (–) level they became the most significant factor in terms of force protection risk (see Table 12, Chapter IV). The Insurgent force is based on events of Bosnia. Clearly for different regions, an Insurgent force’s tactics, techniques and procedures (TTPs), capabilities, and aggressiveness would need to be adjusted. For this model, Insurgents are relatively weak compared to the blue forces. This was the case in Bosnia. However, with today’s operations in Iraq and Afghanistan there is a much stronger association of Insurgents being a formidable force with which to contend. The ability of the analyst to capture the level of aggressiveness exhibited by Insurgents is scenario dependent. The critical data for future analysis is recording detailed activity of blue forces and the TTPs of Insurgents in real-world operations. These measurements can be used to gain accurate insights into possible force protection risks. In Bosnia, with an existing peace agreement between protagonists, the Insurgents were much different than in today’s Middle Eastern environment. In operations across the Middle East there are external actors providing resources, personnel, and information to Insurgents and there are no peace agreements in place. The point is that this research more closely adheres to the definition of Insurgent in the JP 1-02, rather than the connotations used in today’s media from operations in the Middle East (see Appendix A for a definition of Insurgent).

5. Trade-Space Graphs

The plots of mission failure risk and force protection risk used to identify trade-space are useful tools to an analyst or decision maker (see Figures 37, 38, and 39 in Chapter IV). These tools, and the methodology to produce them, are the primary results of the research. They are an example of the simple tools that can be generated using this approach. These graphs take all of the modeling assumptions and data results, and rolls them into simple, easy-to-read graphs. These graphs can be used as aids to a decision maker. Although this paper only discusses downsizing a force, it is possible to use the trade-space tools to assist in determining how and when to increase a force.

However, a political assumption in Stability Operations is that increasing a force is an indication of failure, while decreasing a force is an indication of success. Therefore, it is assumed that force size will primarily be evaluated for downsizing.

A shortcoming with the trade-space graphs in this research is the granularity. The more detailed the plots are, the more useful they will be in identifying the trade-space. Each force size plot should cover the entire range (y-axis) of the graph to allow the most comparisons. For example, in Figure 37 (Chapter IV) the Division is run to a near 99% success at threat level 1. The Brigade is only run to approximately 69% success and the Brigade (–) to 73% success. Had the Brigade and Brigade (–) been run for as long as necessary to achieve 99% success, more comparison could be made with the Division force. If 99% is not possible, the simulation could be run until a force achieves its maximum effectiveness or near steady state. Figure 37, (mission failure risk) plot shows how the lines for each successive day are converging. Once the lines overlap, this indicates the force has achieved its maximum effectiveness, even if given a longer duration to patrol.

Because the simulation is highly accelerated in terms of operational tempo, more measurements are required. Rather than recording MOPs every two days of simulation time, a better interval would be every 6 or 12 hours. This would provide a greater level of fidelity in interpreting the trade-space between forces. This issue is currently a problem with Pythagoras. The ability to extract time series MOEs in a data-farming environment was disabled because of the large amount of data produced. This should be a consideration when determining the intervals within the simulation that data is required to generate the trade-space plots.

Another factor that would increase the fidelity of the trade-space tool is smaller steps in force transitions. Rather than halving the force size at each step (Division to a Brigade to a Brigade (–)), a model could be developed downsizing a Battalion at a time. Depending on the overall size of the operation the step size can be determined based on the fidelity required in the trade-space plots. The results from this research indicate that the force-size steps were too large for detailed analysis in identifying the trade-space.

However, the research demonstrates how simple trade-space tools can be developed. Following the same process used here, trade-space tools can be developed for any operation with greater granularity.

Another anomaly of the force protection risk tool, Figure 38, (Chapter IV) shows that a Division is at a higher force protection risk than a Brigade. This is somewhat counterintuitive, but goes back to the troop posture issue. Because the Division is larger and more dispersed it was engaged more often at influencing and stabilizing the region than the consolidated Brigade force. Therefore, the Division was at a higher force protection risk. The payoff was that the Division achieved greater results in presence. In these terms, Figure 38 is more intuitive; the more engaged a force is at stabilizing a region the better success they will have, but will also be at a greater risk of sustaining casualties. The consolidated Brigade spent a great portion of the time traveling to/from patrol destinations. Their time was not used as effectively in influencing the region. Not only is time money, it is also a measure of force protection risk. The longer a mission takes, the more likely an incident will result in a casualty. Time must not be forgotten as a consideration of risk.

As previously mentioned in Chapter IV, the trade-space tools for mission failure risk and force protection risk should not be analyzed independently. Although the Brigade (–) was able to achieve a greater presence than the Brigade, it was at a greater force protection risk. This indicates to a decision maker that a very mobile or regional quick reaction forces are needed to mitigate the higher force protection risk of the Brigade (–). Both mission failure risk and force protection risk need to be considered in concert with one another, according to the commander's priorities.

C. QUESTIONS TO CONSIDER FOR A FORCE SIZE TRANSITION

The following is a list of questions, based on the framework of the common planning acronym METT-TSL, to be used as a guide for planners when analyzing a force drawdown in any stability operation. The questions may seem intuitive, that any planner would consider, however, it is the M&S effort that really draws out the crucial questions that need to be considered. These questions do not have specific answers as a result of the research. Part of the research was coming up with these questions. Similar to the Generic Intelligence Requirements Handbook (GIRH), the following questions should

steer a planner through the analysis in evaluating different COAs. Answers to these questions will not only assist in the planning, they will also assist in developing a good model from which to develop trade-space tools.

1. Mission

- What are the requirements for future mission success in the operation?
- What specific objectives at the tactical level induce the desired results at the operational and strategic level?
- Are the tactical objectives achievable by the number, disposition and employment of forces?
- What are the acceptable levels for achieving the tactical objectives? Will 75% achieve the desired results or will it take more?
- What initial disposition of forces will maximize presence, while facilitating the eventual drawdown of forces?
- What employment tactic will achieve the greatest presence? Can smaller patrols have the same effect in presence as larger patrols?
- How many patrols and at what rate can they be generated from the force?

2. Enemy

- What is the perceived threat environment?
 - o The threat environment is an arbitrary theoretical scale with the assumption that the situation will improve. With this assumption, the original conditions can be considered the highest and the environment for redeploying can be considered the lowest. This research used a 1 to 10 scale; however, any relative scale will work as long as there is enough parameters to measure to assess where on the scale the threat environment exists
- What is the escalation propensity?
 - o This is consideration of how quickly things become inflamed and get out of hand. This measure is tied very closely to the threat level and the simulation suggests is the most important measure in determining threat levels.
 - o Most likely, escalation is geographically dependent. Not all areas within the AOR will escalate at the same rate. Some areas within the AOR will escalate faster than other areas. Therefore, the estimation of escalation needs to be considered in conjunction with the required presence within areas of the AOR. Although escalation is geographically dependent, it is not static. This means an area of low escalation can quickly change if not monitored closely. This is why the escalation in the simulation was uniform for the entire U.S. AOR, rather than varying degrees of escalation

within sub-regions of the AOR. This phenomenon is seen in both Iraq and Afghanistan today, whereas in the simulation the entire region was exposed to the same escalation—though it need not have been.

3. Terrain/Weather

- What effect does terrain and weather have on patrol mobility?
- What is the average travel time for patrols to reach destinations?
- Are these patrol times weather- or seasonal-dependent?
- Does the terrain allow multiple routes for patrol routes?
- What is the maximum acceptable time for a QRF to respond?
- Where is it feasible to establish military garrisons?

4. Troops and Fire Support Available

- How much presence is required?
- How many troops can achieve this presence?
- What is the best composition of a patrol?
 - Patrol composition can fall anywhere in between the two extremes of large, armored, and heavy patrols to small, light, and mobile patrols?
- What is the relative influence factor of differing patrols?
- Are smaller patrols more effective at swaying the public than larger intimidating forces?
- What is the perceived influence projection of various sized patrols?
- How is force protection risk measured?
- What is the required composition and number of quick reaction forces?

5. Time

- What are the internally imposed timelines?
- What are the externally imposed timelines?
- What is the maximum acceptable time for a QRF to respond?
- What is an acceptable trade-off in time for projected mission completion?
Is it acceptable to downsize to a smaller force if the analysis indicates it should take approximately three times as long?
- How does the longer timeline effect the political and economic considerations to the operation?

6. Space

- What is the most effective disposition of forces to achieve the right balance in presence and force protection?
- What is the minimum acceptable level for area coverage? Is it better to cover 50% of the space 100% of the time or 100% of the space 50% of the time?
- What are the goals in terms of covering space?

7. Logistics

- Is the required Operational Tempo to achieve the desired presence sustainable?
- Is the desired basing strategy supportable?

D. SUMMARY

People make decisions, not models. However, often the model is the foundation for developing insight to provide to a decision maker. This paper presents insights for consideration in downsizing a force in Stability Operations based on information from a model.

Besides providing insight into force transitions, the other goal of this paper is to structure a thought process for considering the threat environment when evaluating when to downsize a force. There will always be the political and economic factors that can override all other considerations in downsizing a force. However, from a military decision-maker's standpoint, the first concerns are the risk of failing the mission, followed by the force protection risk. These two concerns (objectives) are often conflicting. An increase in one objective usually means sacrificing in the other. Therefore, simple tools are needed to compare the trade-offs between the two objectives. The third dimension added to these two objectives is time. An increase or decrease in one of the risk objectives will inevitably effect the duration of the operation. As time increases, often so does risk.

This research has demonstrated the applicability of MAS as an analysis tool in Stability Operations. The Pythagoras model provided the data from which simple graphs were produced to be used as a decision aid in downsizing a force. Referred to as trade-space tools, these graphs are a means to compare conflicting objectives, namely mission success and force protection. Using the trade-space tools in unison, an analyst can hypothesize the consequences of a certain COA. The trade-space tools can be used to

provide quick advice to a decision maker based on real-world measurements. The tools are used to find the proper trade-space or balance between the two objectives and time, in accordance with the commander's priorities.

Many factors and assumptions used to develop the model are subjective. Such things as parameter values for events and Insurgents are based on expert judgment. However, one of the strengths of this analytical approach is if any values or assumptions are questionable, they can easily be changed and the model re-run. There will always be some level of military judgment in this area. The trade-space tool allows one to see the consequences of such judgments.

The insights highlighted by this research also raised many areas for further study. These topics will be discussed in the following chapter.

VI. RECOMMENDATIONS FOR FURTHER RESEARCH

There are many questions raised in this research that are not fully addressed. Therefore, it is necessary to provide some initial thoughts on how they might be addressed in future research. The research described in this paper is proof of a concept or a demonstration of new ways in which Stability Operations can be analyzed. The methodology set forth in this paper should be expanded on. Some of suggestions for further research using MAS in analyzing Stability Operations are outlined below.

A. LARGER DESIGNS OF EXPERIMENT (DOES)

Many of the parameters used in the simulation for both red and blue side are subjective. Therefore, a detailed analysis should be done for these parameters to investigate their influence on the model. This sensitivity analysis can quantify which of the subjective parameters contribute to the outcome of the simulation and those that are not important. This investigation will assist in focusing the discussion on the critical parameters, so time is not wasted on disagreements on parameters that have minimal impact on the outcome.

This research data farmed over combinations of red agent instance (quantity of each of the 12 types of red agents). These parameters are often referred to as “noise” or uncontrollable factors because a decision maker or blue force has no control over them in the real world. In contrast to the “noise” variables are the decision variables (or controllable factors). These are the factors that can be controlled by the decision maker in the real world. None of the blue force parameters were farmed over within each scenario. The comparisons made in blue parameters were the force size and disposition within the three scenarios. To adequately explore which parameters are most crucial to the MOEs larger designs of experiment should be run. New research is being done by the Simulation Experimentation and Efficient Design (SEED) Center for Data Farming⁶⁴ at the Naval Postgraduate School. Currently, efficient designs have explored as many as

⁶⁴ See the SEED Center Website for further information on research efforts of large and efficient DOES. <http://diana.or.nps.navy.mil/~susan/SeedLab/index.html>. Last accessed on 10 September 2006.

48 parameters with multiple levels of each parameter.⁶⁵ In addition to exploring thresholds for QRF or reserve forces to deploy, Table 13 lists recommended parameters to explore using larger designs.

ITEM	ATTRIBUTE	MIN VALUE	MAX VALUE	DECIMAL PLACES
Event	Instance	20	100	0
Event	Detectability A	0	1	2
EventSensor	Max Range	50	500	0
EventSensor	Broadcast Range	50	500	0
Insurgent	Target Value	0	1	2
Insurgent	Target Persistence	0	288	0
Insurgent	Detectability A	0	1	2
Insurgent	Instance	10	100	0
Insurgent	Vulnerability	0	1	2
Insurgent	Average Speed	1	15	0
Insurgent	Marksmanship	0	1	2
Insurgent	Knowledge Retention	0	1000	0
InsurgentWpn	Effectiveness	0	1	1
InsurgentWpn	Max Range	0	50	0
InsurgentSensor	Max Range	50	500	0
InsurgentSensor	Broadcast Range	50	500	0
Escalation	Instance	0	50	0
Escalation	Average Speed	1	15	0
Escalation	Marksmanship	0	1	2
Escalation	Knowledge Retention	0	1000	0
EscalationWpn	Effectiveness	0	1	1
EscalationWpn	Max Range	0	50	0
EscalationSensor	Max Range	50	500	0
EscalationSensor	Broadcast Range	50	500	0
Patrol	Average Speed	1	15	0
Patrol	Marksmanship	0	1	2
Patrol	Knowledge Retention	0	1000	0
Patrol	Target Value	0	1	2
Patrol	Target Persistence	0	288	0
Patrol	Maximum Shooters	1	20	0
PatrolWpn	Effectiveness	0	1	1
PatrolWpn	Max Range	0	50	0
PatrolSensor	Max Range	50	500	0
PatrolSensor	Broadcast Range	50	500	0
AGENTS	MOVEMENT DESIRES			

Table 13. Suggested Factors for Further Data Farming

⁶⁵ Jonathan Roginski, MAJ, USA, "Emergency First Response To A Crisis Event: A Multi-Agent Simulation Approach," Masters Thesis, Operations Research Department, Naval Postgraduate School, Monterey, CA, June 2006, p. 84.

B. RED FORCE DISTRIBUTION

In this research, all of the red force agents were randomly distributed throughout the U.S. sector at the beginning of the simulation. This was based on the assumption that “events” could realistically occur any where at any time. However, in most operations, the J2 is able to focus areas of greater threat. Therefore, it would be more accurate to distribute red forces in accordance with the intelligence threat assessment. If this is done, it will contribute to the validity of the findings and significantly contribute to the analysis of basing options. The basing strategy should be based on the distribution of threats to which patrols are required to respond to.

If there is no intelligence input into higher threat areas when developing a scenario, the distribution of red force agents can be based on population centers or along cultural friction lines. Either approach will have a realistic effect on the decision of how to base the force and conduct patrols.

C. MODEL COMPARISON

One of the unintended contributions of this research was the testing of new versions of the Pythagoras model. In the process of building scenarios and implementing new features of the model, bugs were identified and corrected. This was a big contribution to the improvement of Pythagoras. However, it can not be said with complete certainty that all the features of the model run properly. This is true with many MAS. Therefore, it is recommended to duplicate this study using other MAS, such as Map Aware Non-Automata (MANA).⁶⁶ Comparing results from different models can reinforce findings and/or highlight differences requiring further research.

D. FORCE PROTECTION RISK MEASURES

Both MOPs used in measuring force protection risk have their pros and cons. This is discussed in detail in Chapter IV. To supplement these measures it would be valuable to analyze the number of times a QRF deploys in a scenario. This would indicate how quickly patrols become overwhelmed. Similar to this would be to track the

⁶⁶ MANA is part of the Project Albert suite of MAS. It was developed in 2000 by David Galligan and Michael Lauren for the New Zealand Defence Force. For further information on MANA see the Project Albert Website at <http://www.projectalbert.org/>. Last accessed on 10 September 2006.

number of times patrols return to base prior to their scheduled end of patrol time. Both of these would be fairly simple to implement into Pythagoras and would contribute significantly in “painting” the force protection picture.

Time needs to be used as a measurement of force protection risk. The attribute accumulation helps captures this measure, but time needs to be evaluated on its own.

E. INCLUDING NEUTRALS INTO THE SIMULATION

The point was made earlier that models and simulations should be kept as simple as possible and that more detail should only be added if it is crucial to the research being done. When specifically studying insurgencies, civilians or neutrals would be a crucial addition to the model, since combating an insurgency is all about competing for the support of the population. Patrols compete with Insurgents in influencing the civilians. It boils down to a war of wills.

Success in a counterinsurgency environment is based on winning popular support, not on blowing up peoples’ houses. At the end of the day it all boils down to whether you are fighting the insurgents or the insurgency. Both the insurgency and the military force are competing for the same thing: the support of the people.⁶⁷

This could be modeled in Pythagoras using influence weapons. Both blue force and Insurgent agents have influence weapons that can fire a dose of color or attribute at civilians. It then becomes a tug of war, or battle of determination, to win the civilians’ allegiance.

F. FURTHER INVESTIGATION INTO BASING STRATEGIES

In Bosnia, U.S. forces restructured the positioning of forces to meet their mission requirements. Initially, U.S. Forces built up Eagle Base, near Tuzla, which served as the U.S. sector HQ and was the base camp from which Task Force Eagle conducted all their patrols and garrison activities. Having one central base for military support services was cost efficient; however, patrols were spending a great portion of their time traveling to and from the location of their mission. As the need for presence grew in outer lying areas within their sector, the U.S. built up smaller satellite camps. Although these camps required a build up of military support services, it allowed the commander to posture

⁶⁷ Thomas E. Hicks, “Fiasco,” *Armed Forces Journal*, August 2006, <http://www.armedforcesjournal.com/2006/08/1936008>. Last accessed on 28 August 2006.

forces closer to the areas they were required to patrol. This resulted in less time traveling and more time conducting stabilization operations. It also meant the response time to spontaneous events was shorter.

As U.S. forces reduced their size in the final years of SFOR, they determined it was infeasible to maintain the existing outlying camps. The decision was made to reconsolidate remaining forces at Eagle Base and close down the outer camps. Once this decision was made, planners looked at ways to continue the mission with the remaining forces. The solution was to lease private buildings (base-houses) from which to operate. This allowed a fire team (one-third of a patrol) to maintain a 24/7 presence in the outlying areas and eliminate the long transit times from Eagle Base. Small-sized units would rotate out to the base-house for a week or two at a time to conduct patrolling missions. These small units were essentially self-sufficient, living off the local economy. Other logistical support was still provided by Eagle Base. This innovative approach of posturing forces assumed a greater risk in force protection, but it did mitigate the risk of deteriorating stability by withdrawing forces, and losing the continual presence of peacekeepers.

“Because contingency planning for Peacekeeping Operations (PKOs) is politically unacceptable, improvisation is common when a new mission is established.”⁶⁸ This line from FM 7-98 indicates that combatant commanders do not have much time for detailed planning once given a peacekeeping mission. Therefore, military planners require easy-to-use tools and methods for looking at various basing strategies. These methods need to have an analytical approach to compare the various options and determine which option has the greatest effect on stabilizing a region. In addition, the options need to be evaluated for increased force protection risk.

This research showed that troop basing strategy can be a significant factor in determining the success of the force at projecting presence and achieving stability. There needs to be further investigation into this area. One approach to study the effects different basing strategies have is to use MAS. The methodology would be similar to the process used in this research. An analyst could develop several scenarios all with the

⁶⁸ Headquarters, Department of the Army, FM 7-98, *Operations in a Low-Intensity Conflict*, Washington, D.C.: 19 October 1992, Chapter 4, Section 6, paragraph c, http://www.globalsecurity.org/military/library/policy/army/fm/7-98/F798_5.htm#REF73h2. Last accessed on 5 September 2006.

same size force. Each scenario would vary the disposition of the force to compare the level of area coverage and force protection risk. All scenarios would face the same threat environment, so that the comparisons made are legitimate.

It is already clear that a more dispersed force is better at achieving area coverage, but it is not clear how much better. It is also not clear what are acceptable trade-offs in force protection risk for more dispersion. A study that compares basing strategies can quantify the trade-offs in dispersion (to achieve area coverage) and an increase in force protection risk.

Each basing option has its inherent pros and cons (associated risk); however, this methodology can develop “trade-space” tools similar to this research used to determine an acceptable balance between area coverage and force protection risk. The focus should be on analyzing which posture has the best response times and projects the greatest presence to positively influence stabilization without a significant increase in risk of casualties.

Although the unique approach of using base-houses was designed for short duration (approximately six months), it was very effective and requires exploration as potential doctrine given the right operational environment. The base-house tactic is also similar to the dispersed nature of the Forward Operating Bases (FOBs) in Iraq and Afghanistan. These FOBs can be large-scale bases or small outposts without all the nice-to-have services. The similarity is that this posturing allows forces to maintain a constant presence in a region. Like the FOBs, the base-house can provide both presence and continuity. “It is necessary that troop presence be maintained at high enough levels for stability to spread outward from the areas where it has been achieved.”⁶⁹

This basing concept has similar attributes to the Distributed Operations (DO) doctrine being developed by the Marine Corps Warfighting Lab (MCWL).⁷⁰ A residual

⁶⁹ Christopher Griffin, “View from the FOB, The Perks and Pitfalls of Forward Operating Bases,” *Armed Forces Journal*, June 2006, <http://www.armedforcesjournal.com/2006/06/1813596>. Last accessed on 28 August 2006.

⁷⁰ “A Concept for Distributed Operations,” Marine Corps Warfighting Lab (MCWL), 25 April 2005, <https://www.mccdc.usmc.mil/FeatureTopics/DO/A%20Concept%20for%20Distributed%20Operations%20-%20Final%20CMC%20signed%20co.pdf#search=%22A%20Concept%20for%20Distributed%20Operations%22>. Last accessed on 28 August 2006.

benefit of pursuing this exploration of basing strategies would be contributions to the research being conducted by MCWL on DO.

G. FORCE SIZE VERSUS ISR ASSETS

If the goal in a stability operation is to project presence as a means of bringing about security, then research should focus on enablers that aid in force projection. A large portion of the presence assumption is applying the right force presence, at the right time, in the right place. An increase in ISR capability, particularly human intelligence (HUMINT), can be a force multiplier in achieving presence. Studies can be conducted using MAS to investigate the trade off of increased ISR over increased troop strength as a means of force projection. The hypothesis of such a study would be that increased situational awareness due to greater ISR assets allows a smaller force to apply the right force presence, at the right location, at the right time.

H. GREATER FIDELITY IN TRADE-SPACE TOOLS

As previously discussed in Chapter V, the trade-space tools could benefit from a greater level of fidelity to make comparisons between scenarios to identify the trade-space. There are three simple ways to improve the fidelity of these tools. First, the recording of MOE data should be done at shorter intervals than two days. Every 12 hours would be a better time interval of simulation time for recording data. To do this, it is dependent on enabling the “time series MOEs” within Pythagoras for use in a data-farming environment. The second way to improve the fidelity of the trade-space tool is to step down the force in smaller intervals. Downsizing a force a Battalion at a time more closely follows how it would be conducted in the real world and would provide a greater level of fidelity in the plots. The third recommendation is to run all scenarios until they achieve a steady state. In other words, allow each force to achieve its greatest capability in area coverage. If this is not feasible due to computing power, an analyst can evaluate what is the longest duration possible for the available resources and run the simulation for that period.

I. SUMMARY

This chapter provides ideas for further research into downsizing a force in a Stability Operations. Modeling and Simulation is one of many methods used in operations analysis, and has historically been focused on combat operations. New

approaches such as the methodologies of data farming and this research have demonstrated the applications of simulations to Military Operations Other Than War (MOOTW). All indications suggest that the U.S. military will predominantly be engaged in MOOTW for decades to come. Therefore, it is imperative that analysts explore all possible means for which to study these complex operations.

Issue number 23 of the SFOR Lessons Learned (see Appendix E) highlights the critical assumption of this research: that presence translates into security and eventually stability. Presence is best achieved through mobile patrols that can effectively engage and interact with the population.

This research provides a methodology that enables an analytical framework to be used in evaluating force size reduction in Stability Operations. The framework focuses on three critical areas for consideration: mission failure risk, force protection risk, and time. Using these three areas as dimensions of trade-space, simple tools are generated to assist a planner in comparing the trade-offs in time and risk when downsizing a force. Used simultaneously, a planner can make quick assessments on the right size of a force to minimize the risk of failing the mission and the risk to the force. Based on the commander's priorities, planners can find the right balance of these conflicting objectives with the third dimension of time.

In addition to the creation of the trade-space tools, the resounding conclusion drawn from the research is the overwhelming effect basing strategy has on the efficiency of the force projecting a stabilizing presence. The significance of basing strategy is often lost by planners with the Cold War mentality of collapsing back on positions. The results from the simulations emphasize the importance basing or troop posture had on the ability of the force to project presence. This highlights the fact for decision makers to maintain the focus of "presence" and how to maximize it when downsizing the force. It should be intuitive that achieving presence is the most crucial principal in a Stability Operations. If this were not the case, the force would not bother to deploy.

Even though troop posturing is often overlooked as a significant factor in achieving presence; troop employment is probably more so. Typically, force protection concerns dictate the employment of patrols (size and composition). This approach can result in unnecessarily large patrols that can be both intimidating and limiting on the

number and frequency of patrols generated. If the operational environment is such that large imposing patrols are necessary for the effect of presence, so be it. However, consideration should be given to the effect smaller patrols could have in influencing and building rapport with the population. Smaller patrols are certainly more approachable, with sympathetic locals willing to provide information of operational value. Smaller patrols also allow a force to generate more units to blanket the countryside and achieve presence. The risks of operating smaller more autonomous patrols can be offset by a mobile and responsive QRF, either in the air and/or on the ground.

In conclusion, military planners must look at all the ways in which a Stabilization Force can maximize its projection of presence and maintain that presence near continuously, while simultaneously minimizing the risk to the force and adhering to operational timelines. This is a difficult task due to the dynamic nature of Stability Operations. Therefore, the trade-space graphs were developed to provide a way to assist in simplifying the complex analysis required to make force reduction decisions.

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APPENDIX A. TERMS AND DEFINITIONS

Most of the terms and definitions in this appendix are taken from the following two references.

1. (JP 1-02)

Joint Publication 1-02, DOD Dictionary of Military and Associated Terms
<http://www.dtic.mil/doctrine/jel/doddict/>. Last accessed on 3 September 2006.

2. (DMSO)

Defense Modeling and Simulation Office online glossary
<https://www.dmsomil/public/resources/glossary/>. Last accessed on 3 September 2006.

Agent (Intelligent Agent): A software entity that carries out a set of operations on behalf of a user with some degree of independence or autonomy, and in so doing, employs knowledge or representation of the user's goals or desires. (DMSO)

Agent-Based Models or Simulations: In ABMs or agent-based simulations (ABSs), individual autonomous agents self organize and stochastically interact with each other and their environment, mimicking complex large scale system behavior. Agent-based models are low resolution but can look at many effects over a wide range of possibilities. Some characteristics of ABS are quick scenario setup times and quick iteration run times. Autonomous agents are software objects that move, sense, communicate, shoot, degrade based on defined rules. Each agent has their own local perspective on the environment and set of goals. Each agent's actions are based on achieving their prioritized goals.

Entities/agents are controlled by decision-making algorithms as opposed to the modeller explicitly determining their behavior in advance. Agent-based models are sometimes referred to as Complex Adaptive Systems (CAS) because of the way the entities within them react with their surrounding. See also Multi-Agent Simulations (MAS). (DMSO)

Complex Adaptive System: A dynamic system composed of many nonlinearly interacting parts or agents interacting to achieve their individual goals. Each agent's actions has an affect on other agents and/or their environment. Agents receive feedback through their sensors to modify their behavior. The system evolves according to three key principles: 1. Order is emergent 2. History is irreversible 3. Future is often unpredictable. (DMSO)

Force Protection Risk: The risk of an increased threat to U.S. forces as a result of transitioning from a larger force to a smaller force. (Author definition)

Hostile: In combat and combat support operations, an identity applied to a track declared to belong to any opposing nation, party, group, or entity, which by virtue of its behavior or information collected on it such as characteristics, origin, or nationality contributes to the threat to friendly forces. (JP 1-02)

Insurgent: Member of a political party who rebels against established leadership. (JP 1-02)

Low-Intensity Conflict: Political-military confrontation between contending states or groups below conventional war and above the routine, peaceful competition among states. It frequently involves protracted struggles of competing principles and ideologies. Low intensity conflict ranges from subversion to the use of armed force. It is waged by a combination of means, employing political, economic, informational, and military instruments. Low intensity conflicts are often localized, generally in the Third World, but contain certain regional and global security implications. Also called LIC. (JP 1-02)

Mission Failure Risk: The risk of a smaller force failing to complete the mission that is assumed the larger force would have accomplished. This term is used in reference to a force downsizing. The “mission” is understood to be, establishing security and stability within the area of responsibility. (Author definition)

Operations Research: The analytical study of military problems undertaken to provide responsible commanders and staff agencies with a scientific basis for decision on action to improve military operations. Also called operational research; operations analysis. (JP 1-02)

Operational Environment: A composite of the conditions, circumstances, and influences that affect the employment of military forces and bear on the decisions of the unit commander. Some examples are as follows.

- **Permissive Environment**--Operational environment in which host country military and law enforcement agencies have control as well as the intent and capability to assist operations that a unit intends to conduct.
- **Uncertain Environment**--Operational environment in which host government forces, whether opposed to or receptive to operations that a unit intends to conduct, do not have totally effective control of the territory and population in the intended operational area.
- **Hostile Environment**--Operational environment in which hostile forces have control as well as the intent and capability to effectively oppose or react to the operations a unit intends to conduct. (JP 1-02)

Peace Building: Post-conflict actions, predominately diplomatic and economic, that strengthen and rebuild governmental infrastructure and institutions in order to avoid a relapse into conflict. (JP 1-02)

Peace Enforcement: Application of military force or the threat of its use, normally pursuant to international authorization, to compel compliance with resolutions or sanctions designed to maintain or restore peace and order. (JP 1-02)

Peace Operations (PO): A broad term that encompasses peacekeeping operations and peace enforcement operations conducted in support of diplomatic efforts to establish and maintain peace. (JP 1-02)

Peacekeeping: Military operations undertaken with the consent of all major parties to a dispute, designed to monitor and facilitate implementation of an agreement (ceasefire, truce, or other such agreement) and support diplomatic efforts to reach a long-term political settlement. (JP 1-02)

Peacemaking: The process of diplomacy, mediation, negotiation, or other forms of peaceful settlements that arranges an end to a dispute and resolves issues that led to it. (JP 1-02)

Safe House: An innocent-appearing house or premises established by an organization for the purpose of conducting clandestine or covert activity in relative security. (JP 1-02)

Simulation Environment: a. Consists of the operational environment surrounding the simulation entities including terrain, atmospheric, bathyspheric and cultural information; b. all the conditions, circumstances, and influences surrounding and affecting simulation entities including those stated in a. (DMSO)

Stability Operations: Military and civilian activities conducted across the spectrum from peace to conflict to establish or maintain order in States and regions.⁷¹ Operations that promote and protect U.S. National interests by influencing the threat, political, and information dimensions of the operational environment through a combination of peacetime developmental, cooperative activities and coercive actions in response to crisis.⁷²

Stability And Support Operations (SASO): (Acronym also used to stand for Stability and Security Operations.) The term SASO covers two separate and distinct types of missions. Support Operations provide essential supplies and services to assist designated groups. It relieves suffering and helps civil authorities respond to crises. Stability Operations apply military power to influence the political and civil environment, to facilitate diplomacy, and to interrupt specified illegal activities. Its purpose is to deter or thwart aggression; reassure allies, friendly governments, and agencies; encourage a weak or faltering government; stabilize a restless area; maintain or restore order; and, enforce agreements and policies.⁷³

State: The internal status of a simulation entity (e.g., fuel level, number of rounds, level of physical health). (DMSO)

⁷¹ DoD Directive 3000.05, *Stability, Security, Transition and Reconstruction (SSTR) Operations*, http://www.dtic.mil/whs/directives/corres/pdf/d300005_112805/d300005p.pdf#search=%22dodd%203000.05%22. Last accessed on 3 September 2006.

⁷² <http://www.globalsecurity.org/military/library/policy/army/fm/3-06/gloss.htm>. Last accessed on 3 September 2006.

⁷³ <http://www.globalsecurity.org/military/ops/saso.htm>. Last accessed on 3 September 2006.

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APPENDIX B. PYTHAGORAS PARAMETERS

The following is a compilation of some of the primary parameters used in the Pythagoras model. Screen shots of the Pythagoras GUI are shown to give the reader context to the model. There are many parameters within Pythagoras that were not used in this study. For a complete list and description of the Pythagoras agent-based model refer to the *Pythagoras Users Manual*.⁷⁴

Before describing the Pythagoras parameters a short excerpt from the Pythagoras Users Manual provides a description of the model:

Traditional combat modeling and simulation have concentrated on the physical aspects of combat. Rates of movement, rates of fire, lethality, the effect of weather, terrain, etc., are all phenomena that are measurable to some degree and lend themselves to mathematical representations. However, the combat environment involves not only the physical world, but also human factors (features that motivate soldiers or deter them from engaging in combat) and leadership (the ability to inspire, integrate, and employ soldiers and weapons to attain an objective). The three components are tightly coupled. For example, weapons work best when used by well-trained troops who are directed by enlightened leaders.

Pythagoras was created as a non-traditional model to support the growth and refinement of Project Albert. The goals of the new software were:

1. The software should be able to be used by a Marine History-major with less than eight hours of training.
2. It must implement variables from the fuzzy logic trade space. These variables should be held constant during a particular replicate so that cause and effect relationships could be developed as a result of data farming.
3. The software must be data farmable, i.e. able to run on a distributed computer for 100,000 or more replicates, preferably using XML input and output.

Pythagoras is the result and it incorporates the three goals listed above. It enables a user to create various intelligent agents and assign them behaviors based on motivators and detractors. The agents can either act as individuals or be loosely or tightly controlled by one or more leader agents. Pythagoras is written in Java, making it platform-independent. It can be run in a supercomputer environment as a batch job, enabling tens of thousands of repetitions to be run in a short time; or it can be used and run interactively on a PC through a graphical user interface (GUI).

Pythagoras offers a unique set of capabilities in the area of agent-based simulations:

1. Incorporates *soft rules* to distinguish unique agents
2. Uses *desires* to motivate agents into moving and shooting
3. Includes the concept of *affiliation* (established by *sidedness*, or color value) to differentiate agents into members of a unit, friendly agents, neutrals, or enemies
4. Allows for behavior-changing events and actions (called *triggers*) that may be invoked in response to simulation activities
5. Retains traditional weapons, sensors, and terrain⁷⁵

⁷⁴ Edmund Bitinas, Zoe Henscheid, and Donna Middleton, *Pythagoras User's Manual*, v1.10, Northrop Grumman Mission Systems, May 2006, pp. 302-324.

⁷⁵ Ibid., pp. 22-23.

OVERVIEW TAB

The overview tab (Figure 40) allows the user to set the number of time steps for the simulation to run. The random seed and random index can also be entered here if a particular file from data farming needs further examination.

The only parameter used on the overview tab for this research was the Number of Time Steps. Scenario descriptions are included as a quick reference of the scenario design in the XML scenario file developed in this thesis. The random seed, which alters the variable parameters at run start, is changed in the study file when submitted for data farming via the MHPCC super computer.

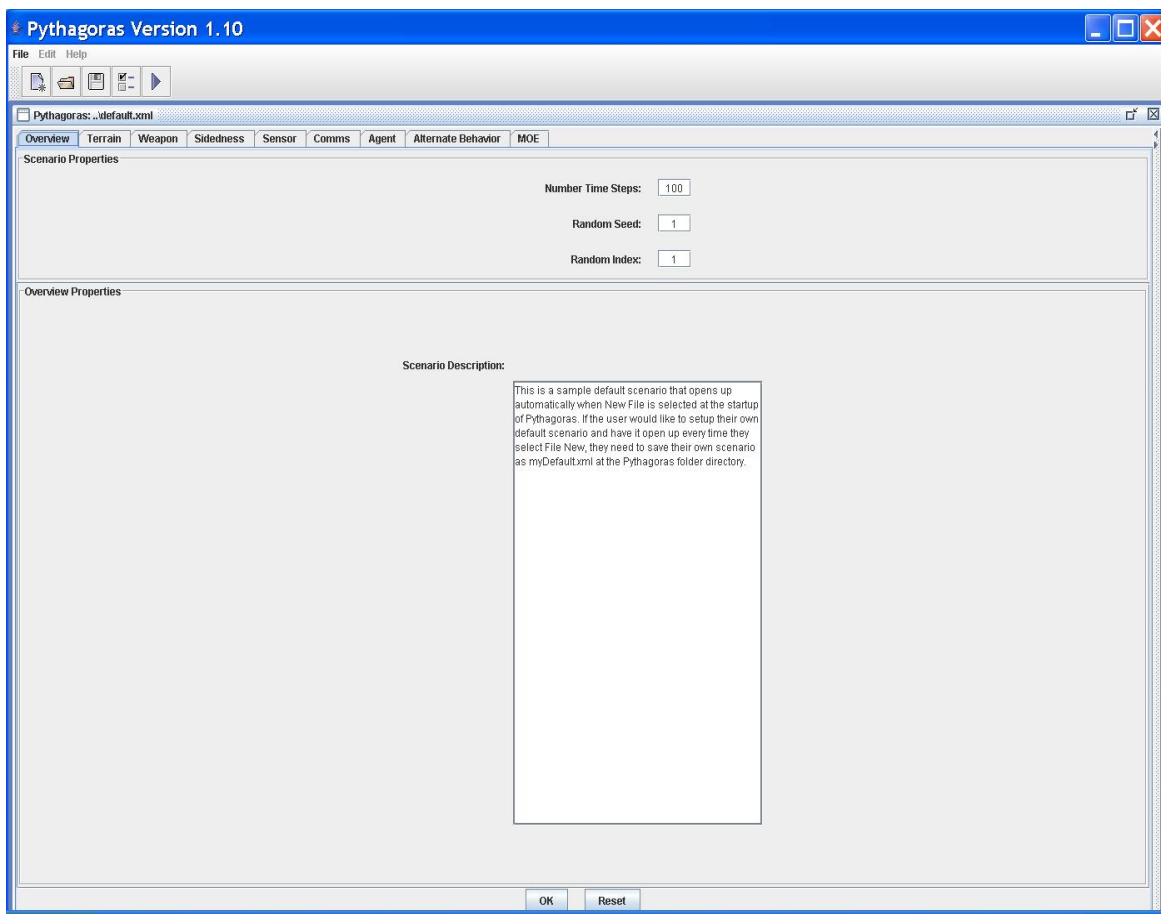


Figure 40. Overview Tab

TERRAIN TAB

The terrain tab (Figure 41) allows the user to construct the terrain on which the agents react to. The “Basic Properties” sub-tab has the parameter settings for the basic terrain that covers the entire play board (agent movement space). The

“Feature Properties” sub-tab has the parameter settings for individual terrain features within the scenario. For example, buildings, roads, water, bridges, mountains, etc. Terrain can provide cover (protection) and concealment as well as limit an agent’s mobility (movement factor).

In all the scenarios of this research terrain was not used. Initial attempts were made to develop a representative road network, linking all the towns and villages of the U.S. sector in Bosnia. This proved to be too difficult for agents to navigate in a realistic fashion and therefore was abandoned. It was also determined to be more detail than was necessary for the question being studied. The only terrain that appears in the graphic representation of the simulation is a JPEG background file of the U.S. sector. This enabled the proper special representation of the scenario being modeled. Although the exact paths of agents’ movements did not adhere to roads in the sector, the distances they covered and the speeds of travel were realistic values for real-world events.

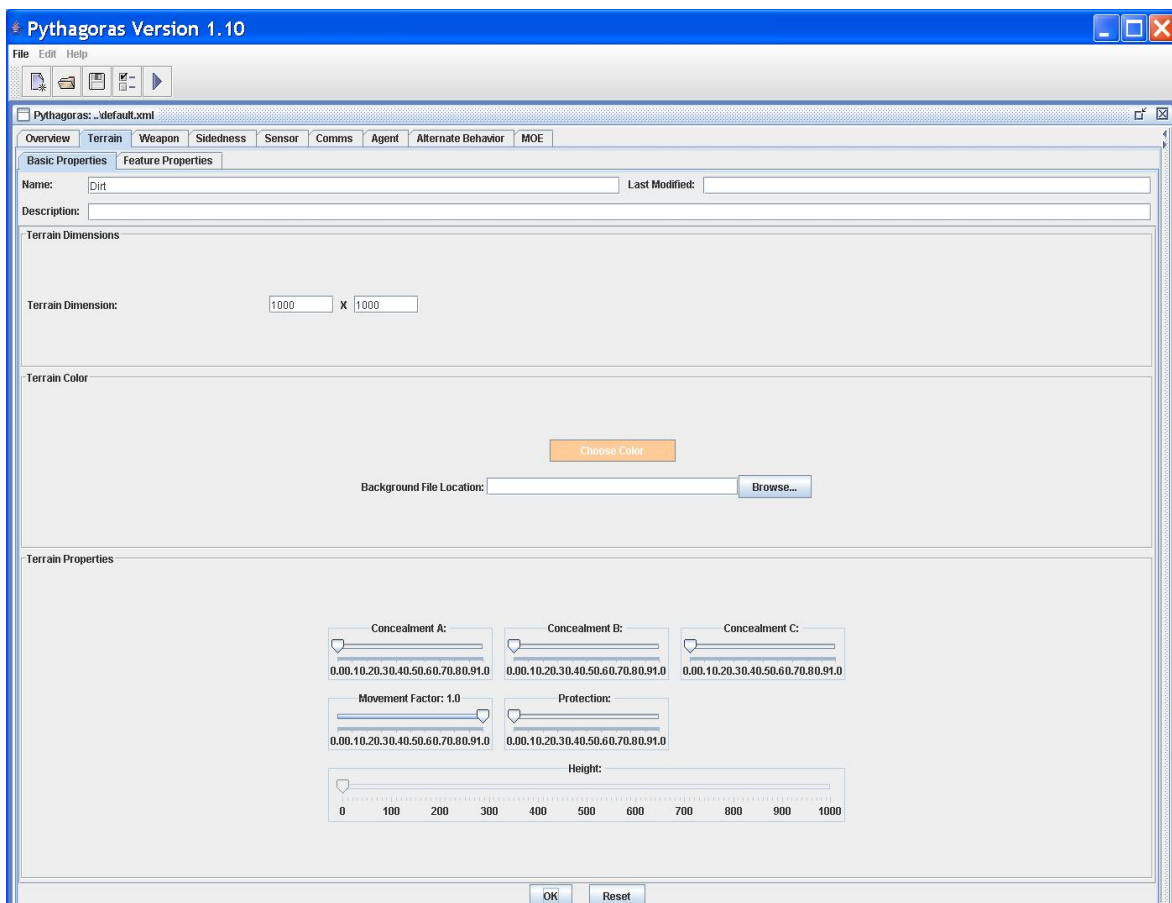


Figure 41. Terrain Feature Tab

The 1,000 pixel x 1,000 pixel terrain box covers an area 81 miles x 81 miles of the U.S. sector in Bosnia. This results in one pixel equal to a 130 meters x 130 meters square. With time defined to be 2½ minutes per time-step, the speed of a pixel per time-step is roughly equal to three kilometers per hour (KPH). For a further breakdown of time, speeds, and distance see Figure 42.

DISTANCE				
Pixel =	Miles =	Yds=	Kilometers =	Meters
1	0.08	143	0.13	130
5	0.41	713	0.65	652
10	0.81	1,426	1.30	1,304
20	1.62	2,851	2.61	2,607
30	2.43	4,277	3.91	3,911
40	3.24	5,702	5.21	5,214
50	4.05	7,128	6.52	6,518
100	8.10	14,256	13.04	13,036
200	16.20	28,512	26.07	26,071
400	32.40	57,024	52.14	52,143
500	40.50	71,280	65.18	65,178
700	56.70	99,792	91.25	91,250
1,000	81.00	142,560	130.36	130,357

TIME			
Time-Step =	Minutes =	Hours =	Days
1	2.5	0.04	0.00
2	5.0	0.08	0.00
3	7.5	0.13	0.01
4	10.0	0.17	0.01
5	12.5	0.21	0.01
6	15.0	0.25	0.01
7	17.5	0.29	0.01
8	20.0	0.33	0.01
9	22.5	0.38	0.02
10	25.0	0.42	0.02
50	125.0	2.08	0.09
55	137.5	2.29	0.10
60	150.0	2.50	0.10
65	162.5	2.71	0.11
70	175.0	2.92	0.12
75	187.5	3.13	0.13
80	200.0	3.33	0.14
85	212.5	3.54	0.15
90	225.0	3.75	0.16
95	237.5	3.96	0.16
100	250.0	4.17	0.17
200	500.0	8.33	0.35
300	750.0	12.50	0.52
400	1,000.0	16.67	0.69
500	1,250.0	20.83	0.87
576	1,440.0	24.00	1.00
600	1,500.0	25.00	1.04
700	1,750.0	29.17	1.22
800	2,000.0	33.33	1.39
900	2,250.0	37.50	1.56
1,000	2,500.0	41.67	1.74
1,152	2,880.0	48.00	2.00
2,304	5,760.0	96.00	4.00
3,456	8,640.0	144.00	6.00
4,608	11,520.0	192.00	8.00
5,760	14,400.0	240.00	10.00

SPEED		
Pixels/Time-Step	MPH	KPH
1	2	3
2	4	6
3	6	9
4	8	13
5	10	16
6	12	19
7	14	22
8	16	25
9	17	28
10	19	31
11	21	34
12	23	38
13	25	41
14	27	44
15	29	47
16	31	50
17	33	53
18	35	56
19	37	59
20	39	63

Figure 42. Time, Speed, and Distance Breakdown for the Simulation

WEAPONS TAB

The Weapons tab (Figure 43) allows the user to build weapons that are assigned to agents. Pythagoras offers a great deal of flexibility in a weapon's functionality. Weapons can be lethal or nonlethal and have direct or indirect fire capability. Weapons can also be restorative, simulating agents providing medical or health-giving services. Influence Weapons can also be created to impart a degree of influence over other agents through a color or generic attribute change.

Pythagoras Version 1.10

File Edit Help

Pythagoras: _default.xml

Overview Terrain **Weapon** Sightedness Sensor Comms Agent Alternate Behavior MOE

Weapon List

Basic

New
Clone
Delete

Name: Basic Last Modified:

Description:

Basic Properties PK Properties

Restorative Weapon: ☐

Effectiveness: 1.0

Fire Rate: 1.0

Maximum Engaged Range: 1000.0

Ammunition Rounds: 1000

Random Damage Degree: 1.0

Suppression Duration: 0

Relative Color Change ☐

Delta Red: 0

Delta Green: 0

Delta Blue: 0

Relative Attribute Change ☐

Delta Alpha: 0

Delta Beta: 0

Delta Gamma: 0

Weapon Targeted Against:

☐ Unit Members

☐ Friends

☒ Enemies

☐ Neutrals

OK Reset

untitled - Paint

Figure 43. Weapon Tab

Table 14 gives a list of all the weapons used in the simulation along with some of the key parameters. Parameters not listed in Table 14 had the same values for all weapon systems. These parameters and settings include:

- Fire Rate 1.0 (shots per time step)
- Ammunition Rounds 1000 (maximum number of rounds)
- Random Damage Degree 0.0 (amount of damage is deterministic)
- Suppression Duration 0.0 (Amount of time that an agent hit will be in a disabled state)

Hit Probability (P_{hit}) and Kill Probability (P_{kill}) for all weapons are 1.0, for range 0 to maximum weapon range. This means that if a target is in range of a weapon, it will be hit and it will be damage with a probability of 1. The amount of damage is dependent on the damage function.⁷⁶

To ensure agents did not run out of rounds for their ‘influence weapons’, each agent was given multiple copies of a weapon. When one ran out of ammunition they would switch to a new one. Currently, Pythagoras does not have the ability to resupply ammunition to agents or allow a weapon to initialize with more than 1,000 rounds. This is most likely because the developers did not foresee many scenarios running beyond 1,000 time steps.

	Lethal/Restorative	Effectiveness	Range	Targeted Against	Relative Attribute Change
BaseRestoreWpn	Restorative	1.000	10	Unit, Friendlies	0
BaseWpn	Lethal	0.500	50	Enemies	0
CampWpn	Lethal	0.500	25	Enemies	0
EscalationWpn	Restorative	0.010	20	Unit, Friendlies	0
EventWpn	Lethal	0.005	20	Enemies	0
InsurgentWpn	Lethal	0.005	20	Enemies	1 α
PatrolWpn	Lethal	0.010	20	Enemies	1 β
QRFWpn	Lethal	0.500	20	Enemies	0
BaseHouseWpn	Lethal	0.500	10	Enemies	0

Table 14. Weapons Used within the Simulation

SIDEDNESS TAB

The Sidedness tab (Figure 45) allows the user to determine how agents view one another. Agent Sidedness (affiliation) is determined by the agent’s color combination of

⁷⁶ The damage function takes many parameters into account to calculate the actual damage to an agent. The formulas can be found on pp. 59-61 of the *Pythagoras User’s Manual*.

red, green and blue. The user decides the color radius (how far away in the color spectrum) for which that agent views other agents as unit members, friendlies, neutrals or enemies. This concept is best represented by Figure 44, which shows an agent defined in two dimensions (blue and green). A defined distance (color radius) from that agent will determine who that agent views as part of its unit, friendly forces, neutrals, or enemies. The sidedness of agents can be static or dynamic in the simulation. For the scenarios of this study all agent affiliations remained static. The initial settings and how the agents view each other can be found in Table 15 and 16. All patrol agents are assigned a sidedness according to the camp from which they are based.

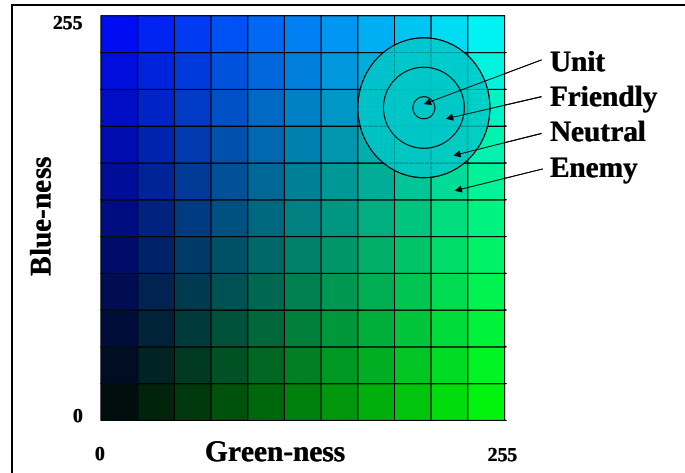


Figure 44. Color Affiliation of Agents within Pythagoras

				Unit				Friendly				Enemy			
Agent Name	Red	Green	Blue	Color Radius	Use Red	Use Green	Use Blue	Color Radius	Use Red	Use Green	Use Blue	Color Radius	Use Red	Use Green	Use Blue
EagleBase	0	0	255	1	0	0	1	100	0	0	1	1	1	0	0
CampDoboj	0	0	250	1	0	0	1	100	0	0	1	1	1	0	0
CampBijela	0	0	245	1	0	0	1	100	0	0	1	1	1	0	0
CampUgijevik	0	0	240	1	0	0	1	100	0	0	1	1	1	0	0
CampKladanj	0	0	235	1	0	0	1	100	0	0	1	1	1	0	0
CampZenica	0	0	230	1	0	0	1	100	0	0	1	1	1	0	0
Event	255	0	0	1	1	0	0	100	1	0	0	1	0	0	1
Insurgent	250	0	0	1	1	0	0	100	1	0	0	1	0	0	1
Escalation	245	0	0	1	1	0	0	100	1	0	0	1	0	0	1

Table 15. Agent Color Combinations and Color Radii

	Eagle Base	Camp Doboј	Camp Bijela	Camp Ugijevik	Camp Kladanj	Camp Zenica	Event	Insurgent	Escalation
Eagle Base	--	FRIEND	FRIEND	FRIEND	FRIEND	FRIEND	ENEMY	ENEMY	ENEMY
Camp Doboј	FRIEND	--	FRIEND	FRIEND	FRIEND	FRIEND	ENEMY	ENEMY	ENEMY
Camp Bijela	FRIEND	FRIEND	--	FRIEND	FRIEND	FRIEND	ENEMY	ENEMY	ENEMY
Camp Ugijevik	FRIEND	FRIEND	FRIEND	--	FRIEND	FRIEND	ENEMY	ENEMY	ENEMY
Camp Kladanj	FRIEND	FRIEND	FRIEND	FRIEND	--	FRIEND	ENEMY	ENEMY	ENEMY
Camp Zenica	FRIEND	FRIEND	FRIEND	FRIEND	FRIEND	--	ENEMY	ENEMY	ENEMY
Event	ENEMY	ENEMY	ENEMY	ENEMY	ENEMY	ENEMY	--	FRIEND	FRIEND
Insurgent	ENEMY	ENEMY	ENEMY	ENEMY	ENEMY	ENEMY	FRIEND	--	FRIEND
Escalation	ENEMY	ENEMY	ENEMY	ENEMY	ENEMY	ENEMY	FRIEND	FRIEND	--

Table 16. Agent Affiliation Based on Color Combination and Color Radii

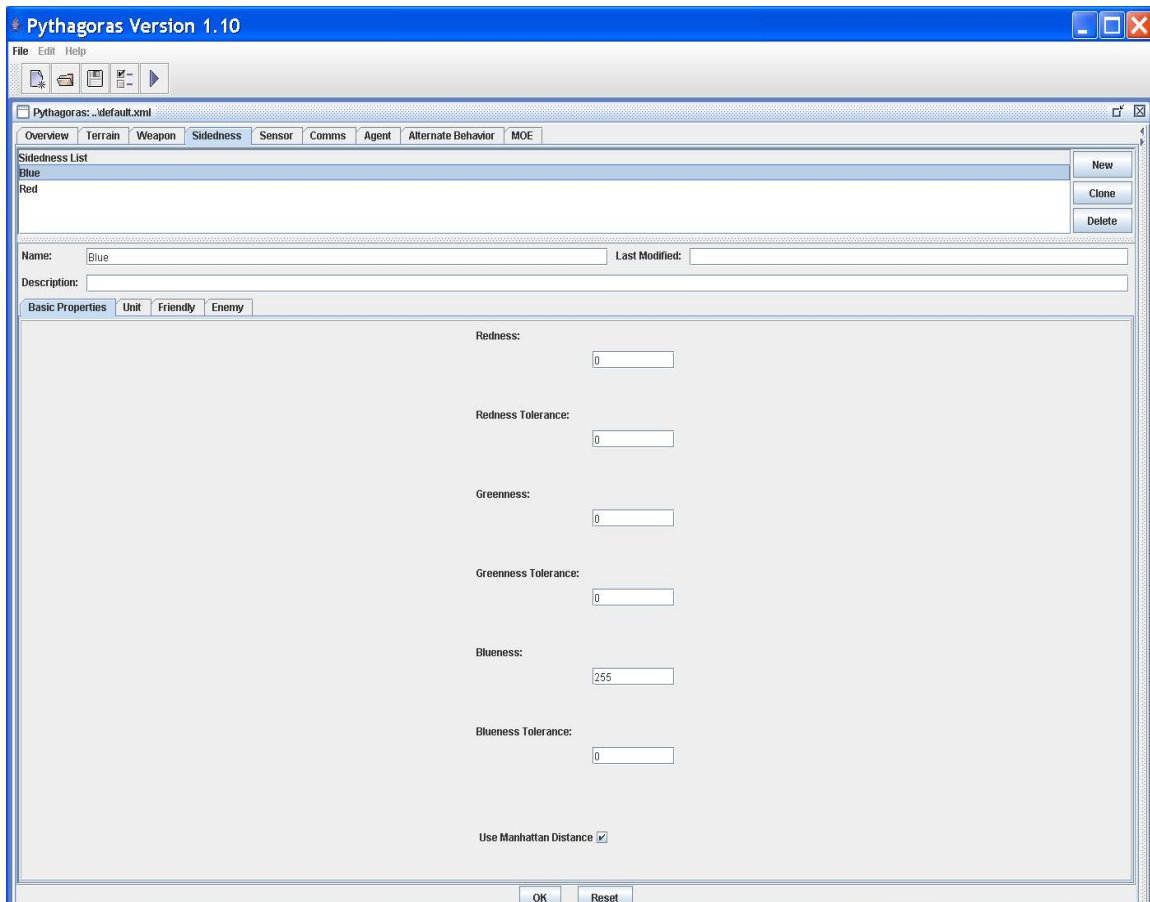


Figure 45. Sidedness Tab

SENSOR TAB

The Sensor tab (Figure 46) allows the user to build sensors that are assigned to agents. Sensors are given one of three signature types. The signature types are user defined, such as visual spectrum, thermal, and infrared. The broadcast range of a sensor is a surrogate for communications. If a broadcast range is given the agent will broadcast

what that particular sensor is detecting to other friendly agents. Sensors can be given a user defined Probability of Detection distribution. Likewise, the user can define a Target Location Error to a sensor, which can introduce an error in location of a detected agent. For example, the further out a detection is made, the greater the chance that the coordinates of the agent detected or a bit off from the detected agent's true location. View Properties sub-tab allows the user to define the field of view of individual sensors.

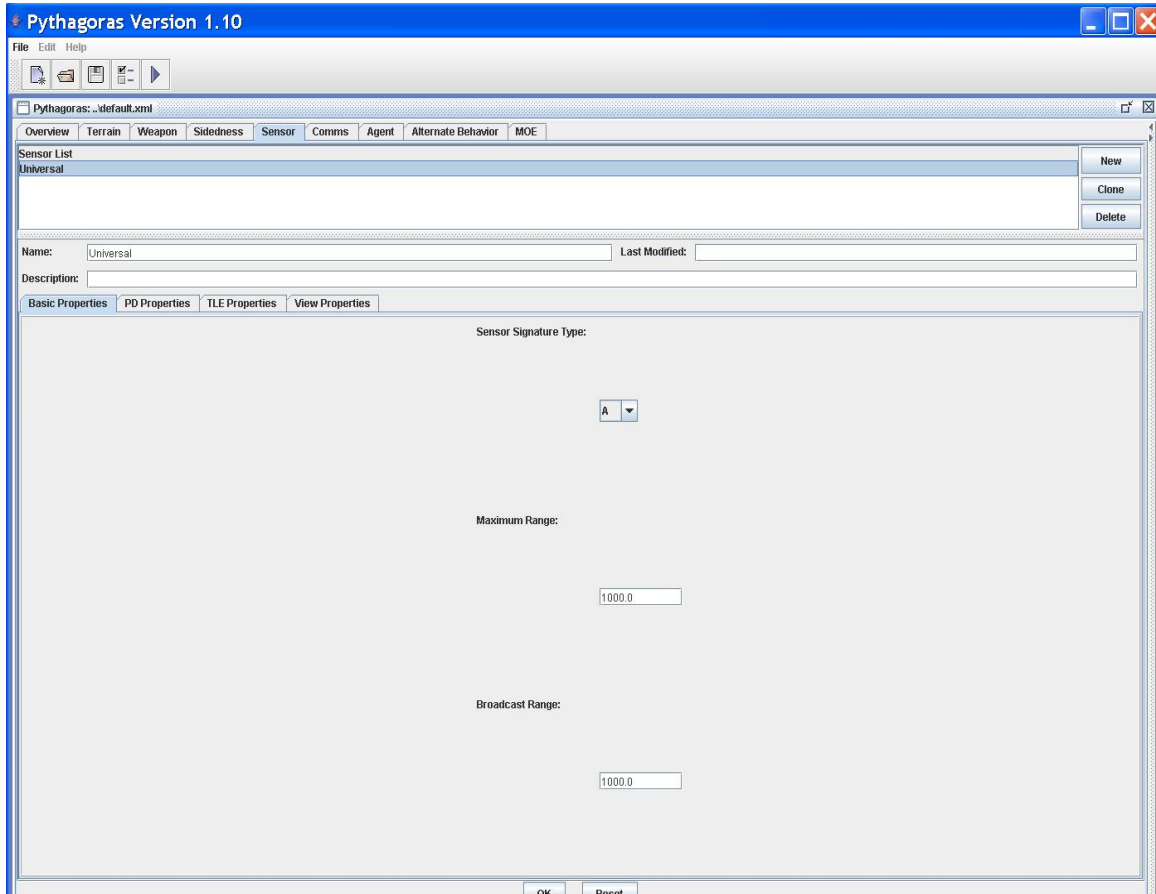


Figure 46. Sensor Tab

The Sensors and their settings used in all three scenarios are shown in Table 17.

	Sensor Range (pixels)	Broadcast Range (pixels)	Pd Properties⁷⁷	Target Location Error (TLE)⁷⁸	View Properties
Base Sensor	200	500	0/1.0 – 200/1.0	0/0.0 – 200/0.25	360° look
Camp Sensor	100	500	0/1.0 – 100/1.0	0/0.0 – 200/0.25	360° look
Base-House Sensor	50	500	0/1.0 – 50/1.0	0/0.0 – 200/0.25	360° look
DIV Patrol Sensor	100	100	0/1.0 – 100/1.0	0/0.0 – 100/0.25	360° look
BDE Patrol Sensor	75	100	0/1.0 – 75/1.0	0/0.0 – 75/0.25	360° look
BDE (–) Patrol Sensor	50	100	0/1.0 – 50/1.0	0/0.0 – 50/0.25	360° look
QRF Sensor	500	0	0/1.0 – 500/1.0	0/0.0 – 500/0.0	360° look
Insurgent Sensor	200	200	0/1.0 – 200/0.75	0/0.0 – 200/0.25	360° look
Event Sensor	20	20	0/1.0 – 20/0.75	0/0.0 – 20/0.1	360° look
Escalation Sensor	300	0	0/1.0 – 300/1.0	0/0.0 – 300/0.25	360° look

Table 17. Sensors Used in the Simulation

COMMUNICATIONS TAB

The Communications tab (Figure 47) allows the use to build communication capabilities that are assigned to agents. Communications can range from simulated human voice to line-of-sight radios, to digital data links. Anything that transmits and receives information can be simulated in the communications tab. The communications feature was not used in this research because the broadcast range of sensors was used in its place. In essence, all agents had perfect communications out to their sensor broadcast range. Whatever an agent detects with his sensor he can transmit that information out to the sensor broadcast range.

⁷⁷ To read the Pd column, the first number is the range and the second number is the probability of detection. For example, for an Insurgent sensor the probability distribution is linear from range 0 (100% Pd) to range 200 (75% Pd).

⁷⁸ To read the TLE column, the first number is the range and the second number is the TLE. For example, for an Insurgent sensor the TLE distribution is linear from range 0 (0% location error) to range 200 (25% location error).

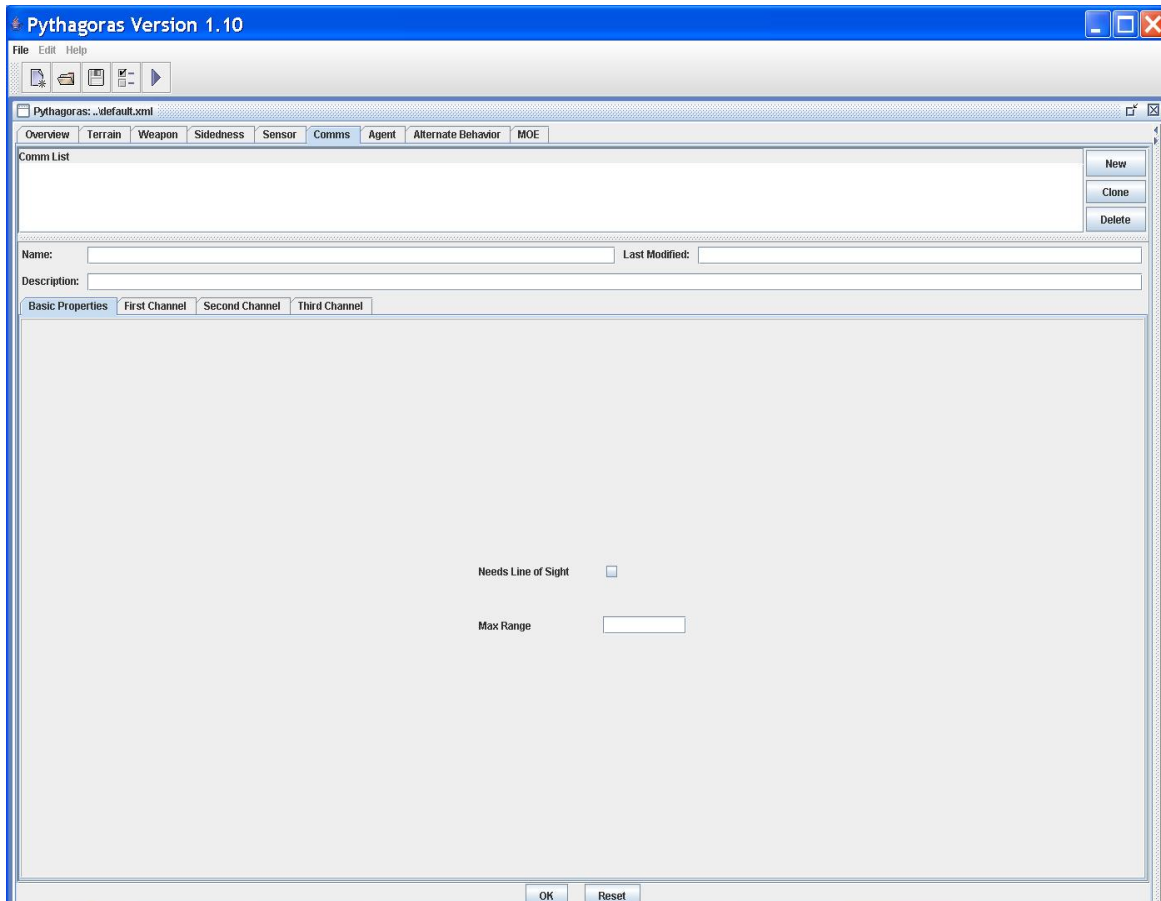


Figure 47. Communications Tab

AGENT TAB

The Agent tab (Figure 48) allows the user to build individual agents and their associated properties, to include weapons assignment, sensor assignment, communications equipment, and behavior desires.

In addition to abstract ideas, agents can also be inanimate objects like a landing beach obstacle or land mine, or bomb aim points.⁷⁹ Often inanimate objects, like obstacles, can be added as a terrain feature. But, if the obstacle alters it's own or another agents behavior due to interactions, the user can create the obstacle as an agent instead of a terrain feature.

⁷⁹ Ryan Paterson and Edmund Bitinas, "Surf Zone/Beach Zone (SZ/BZ) Obstacle Reduction," *Maneuver Warfare Science 2003*, United States Marine Corps, Project Albert, Horne & Johnson (eds.), p. 23.

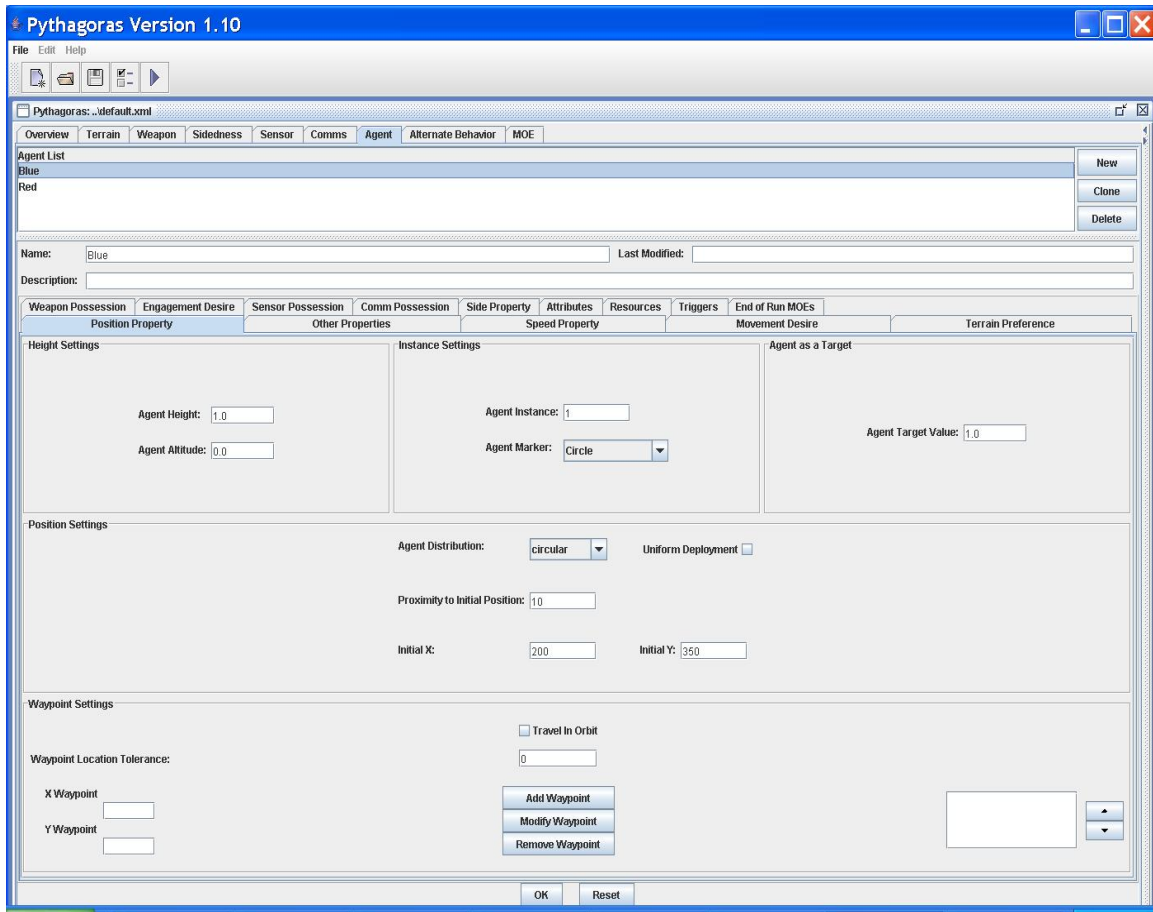


Figure 48. Agent Tab

END OF RUN MOES

In the “End of Run MOE” sub-tab (under the “Agent” tab) the user can select a wide range of values to be recorded at the end of the simulation run. For each scenario in this research, the following values were recorded.

- Event 1-10: Initial Alive
- Event 1-10: Final Injured
- Event 1-10: Final Dead
- Event 1-10: Final Amount of Alpha (generic attribute)
- Insurgent: Initial Alive
- Insurgent: Final Injured
- Insurgent: Final Dead
- Insurgent: Final Amount of Alpha (generic attribute)

- Escalation: Initial Alive
- Patrols: Initial Alive
- Patrols: Final Injured
- Patrols: Final Amount of Beta (generic attribute)
- QRF: Number of Kills

ALTERNATE BEHAVIOR TAB

The Alternate Behavior tab (Figure 49) allows the user to create other behaviors for individual agents. All agents start in their initial behavior, which is defined in all the sub-tabs within the “Agent” tab. The user then defines “triggers” which alter the agent’s behavior from the current behavior to the “alternate behavior” defined in the trigger. There is no limit to the number of alternate behaviors the user can define. An example of a trigger to an alternate behavior is an agent who is patrolling altering his behavior once he is shot at (defined trigger). The new behavior defines all the new desires to shoot, move and communicate. Within Alternate Behaviors the user can redefine any agent attribute that is in the initial behavior. Examples of the cycle of alternate behaviors for patrol agents can be seen in Figures 16 and 17 in Chapter II.

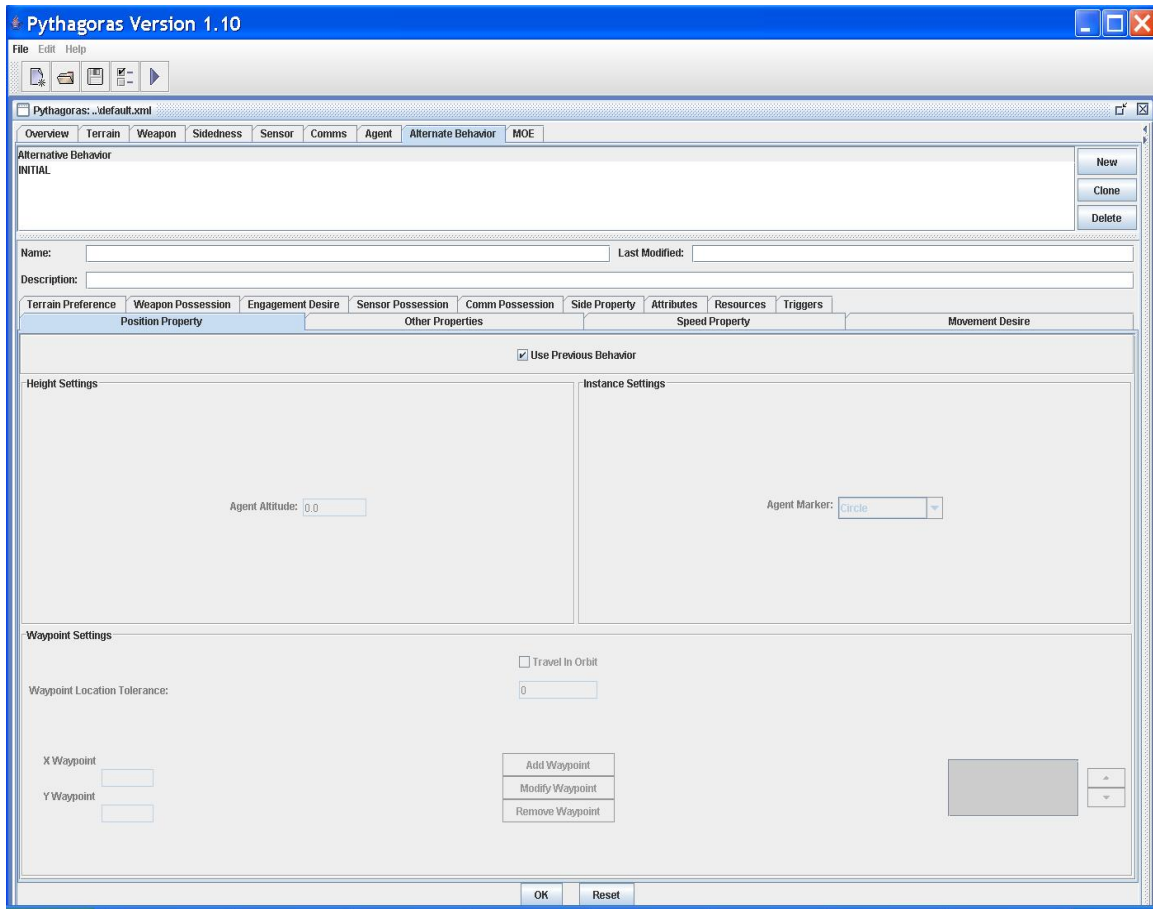


Figure 49. Alternate Behavior Tab

MEASURES OF EFFECTIVENESS (MOEs) TAB

The MOE tab (Figure 50) allows the user to record specific “time series MOE” values at defined intervals within a simulation run. For example, a user can specify to record an agent’s generic attribute level every 100 time steps for a 1,000 time step duration simulation. The resulting data file would provide the initial attribute level at time equals 0 and every 100 time steps thereafter.

Unfortunately, this capability of Pythagoras is not enabled at the MHPCC for the data-farming environment and therefore was not used. Instead, each scenario was run for several durations and the end of run data was strung together to mimic receiving time series MOEs. This is discussed in Chapter III.

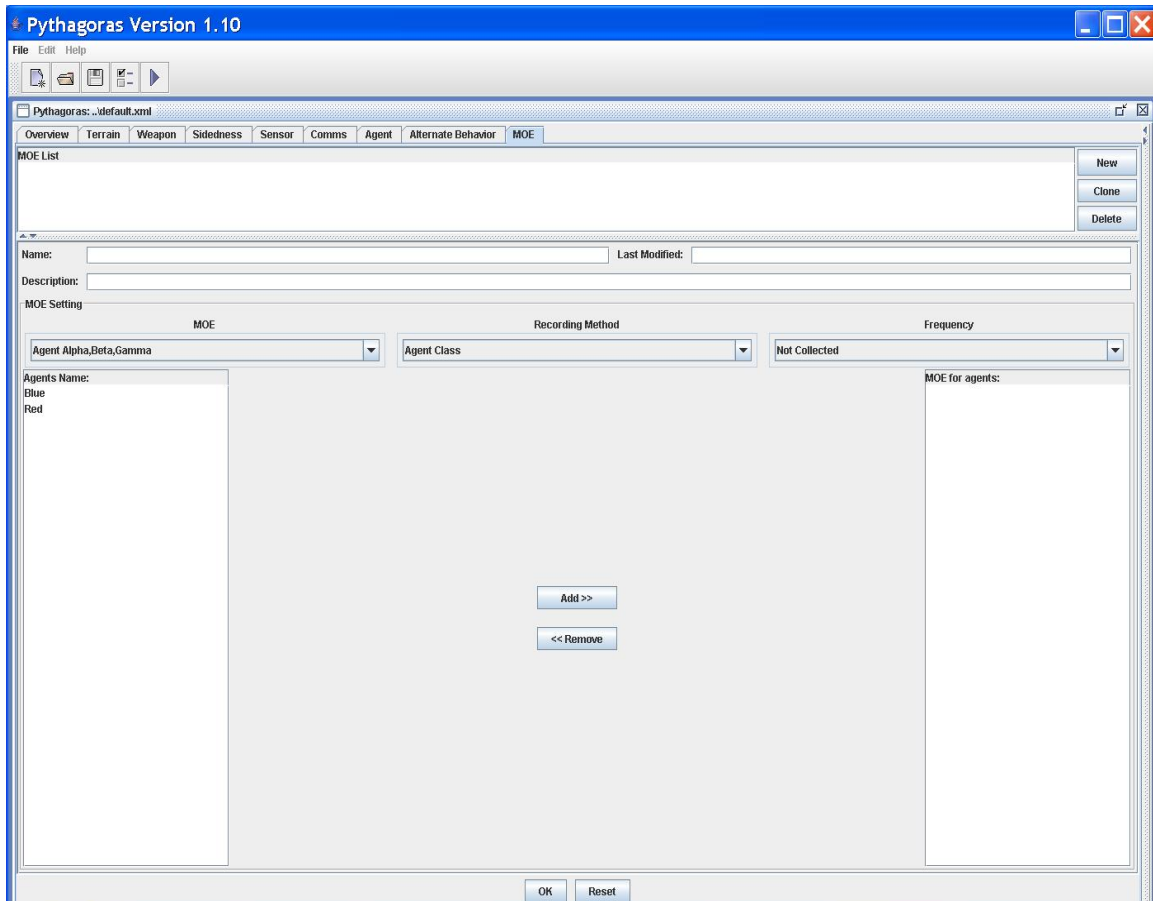
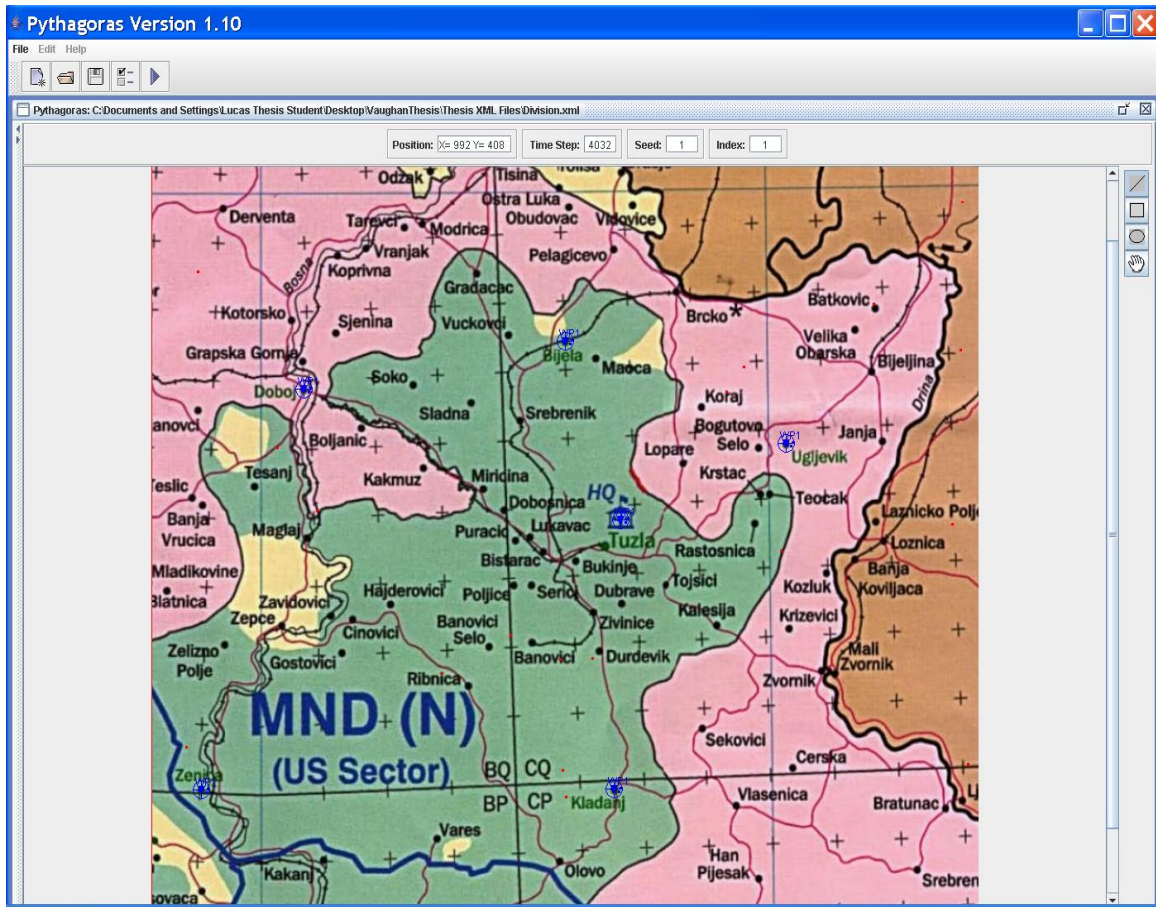


Figure 50. MOE Tab in Pythagoras

TERRAIN CANVAS

The graphical view within the Pythagoras GUI is referred to as the terrain canvas (Figure 51). The terrain canvas is a mapping area that displays the terrain data, agent location, and waypoint location that has been entered in the GUI. This graphic assists the user as the scenario is created by verifying proper locations. Figure 51 shows a background JPEG on the terrain canvas of the U.S. sector in Bosnia. Agent starting locations were determined from the x, y position on the terrain canvas. Other than the background file, no terrain features were used in the scenarios.



PLAY-FORWARD TOOL

The Play-Forward tool (Figure 52) within the GUI allows the user to visually watch a scenario run. Using this tool is the most effective way to verify your scenario and agent behavior. While the Play-Forward tool is running, the user can select an individual agent and view its important parameters as shown in Figure 52. The user can also select to view shots fired, waypoints, and detections of other agents.

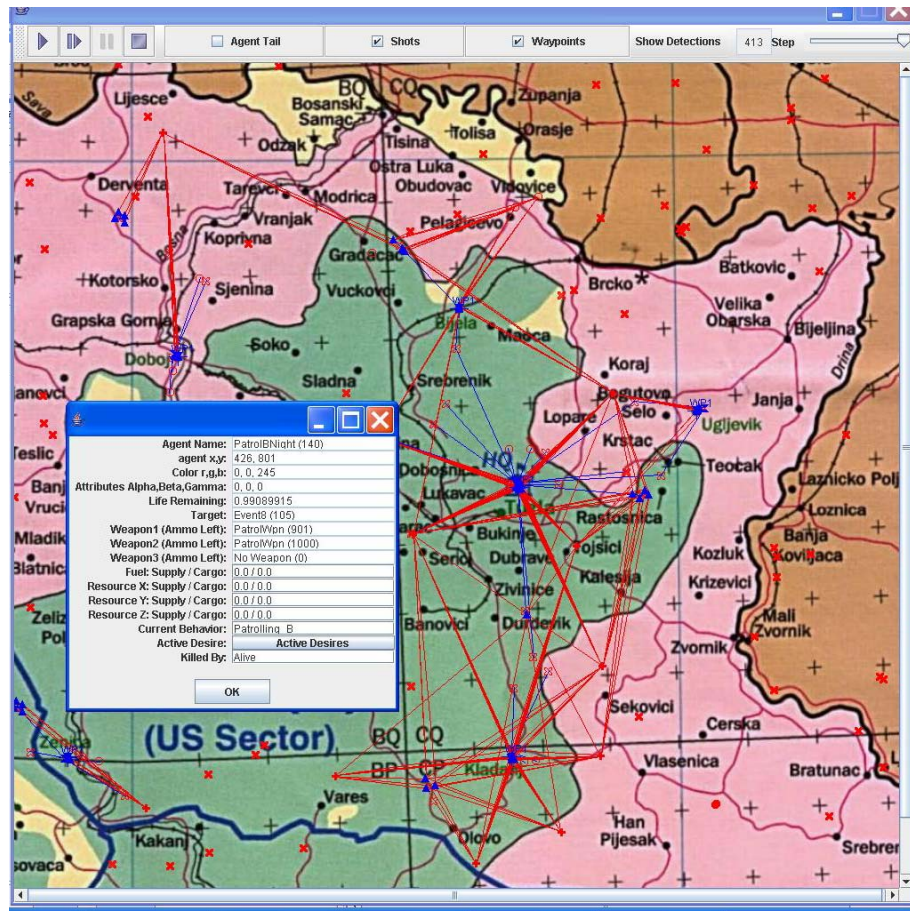


Figure 52. Play-Forward Tool View of Division Scenario

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APPENDIX C. PPLEMENTAL ANALYSIS ON FORCE PROTECTION RISK

The following analysis is supplemental to the results presented in Chapter IV. This additional analysis contributes to the insight on force protection risk; however, it is not viewed as significant as the analysis presented in Chapter IV and therefore has been included in this appendix. It was determined that the percent of injured patrols was not as significant an MOP for force protection risk as the Attribute Accumulation MOP. This is because the Injured patrols MOP is a snapshot in time, namely the end of the simulation run. In contrast, the Attribute Accumulation MOP captures the negative impact on the patrols throughout the entire simulation. In addition, the percent of injured patrols is not a good comparison measure. Because the force sizes are so different, a small percentage can result in very different real numbers of patrols injured. It is not comparable to say that 5% casualties is the same, when in a Division Force that equates to 4.2 patrols (or $4.2 \times 18 = 75.6$ soldiers); in a Brigade it equates to 3.2 patrols (or $3.2 \times 12 = 38.4$ soldiers); and in a Brigade (–) it equates to 1.8 patrols (or $1.8 \times 6 = 10.8$ soldiers). The comparison of injured patrols is broken down in Table 18.

	Division Scenario has 84 Patrol Agents (18 soldiers/patrol agent)	Brigade Scenario has 63 Patrol Agents (12 soldiers/patrol agent)	Brigade (–) Scenario has 35 Patrol Agents (6 soldiers/patrol agent)
Percent Injured			
0%	0.0	0.0	0.0
5%	4.2	3.2	1.8
10%	8.4	6.3	3.5
15%	12.6	9.5	5.3
20%	16.8	12.6	7.0
25%	21.0	15.8	8.8
30%	25.2	18.9	10.5
35%	29.4	22.1	12.3
40%	33.6	25.2	14.0
45%	37.8	28.4	15.8
50%	42.0	31.5	17.5
55%	46.2	34.7	19.3
60%	50.4	37.8	21.0
65%	54.6	41.0	22.8
70%	58.8	44.1	24.5
75%	63.0	47.3	26.3
80%	67.2	50.4	28.0
85%	71.4	53.6	29.8
90%	75.6	56.7	31.5
95%	79.8	59.9	33.3
100%	84.0	63.0	35.0

Table 18. Comparison of Numbers of Patrols for Percent of Force Injured

Figures 53, 55, and 57 show the regression trees for the three scenarios. A summary of the significant factors for the regression trees is shown in Table 19. Like the analysis on the Patrol Attribute MOP for force protection risk, Escalation is the dominant factor. Escalation is followed by the instance of Level 10 Events. It is not clear why the Level 7 and 8 Events seen in Figure 57 outweigh the contribution of Level 10 Events. One possible reason is that the random distribution of Event agents placed more of Event Level 7 and 8 closer to the garrisons of the Brigade (–) force and therefore had greater interactions with the patrols than Level 9 and 10 Events.

Figures 54, 56, and 58 are the corresponding contour plots for the most important parameters in each regression tree. The near vertical color banding in all three contour plots indicate the overwhelming importance of Escalation over other factors in influencing the outcome of percent of injured patrols.

Scenario	1 st Significant Parameter	2 nd Significant Parameter
Division	Escalation	Level 10 Event
Brigade	Escalation	Level 10 Event
Brigade (–)	Escalation	Level 7 Event

Table 19. Comparison of Regression Trees in Terms of Force Protection Risk (Injured Patrols)

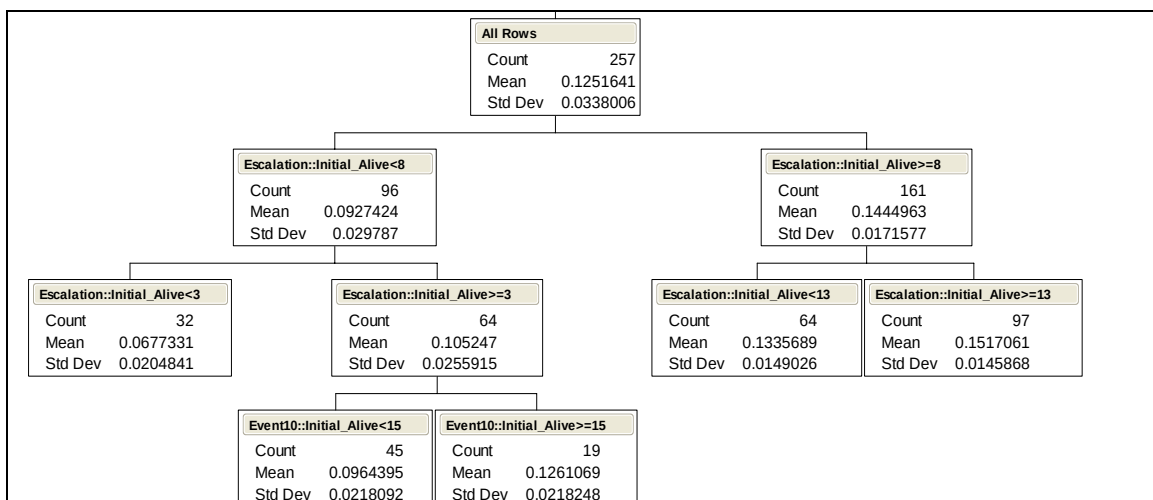


Figure 53. Division Scenario Regression Tree Showing Four Partitions of Data for % Injured Patrol (Force Protection Risk)

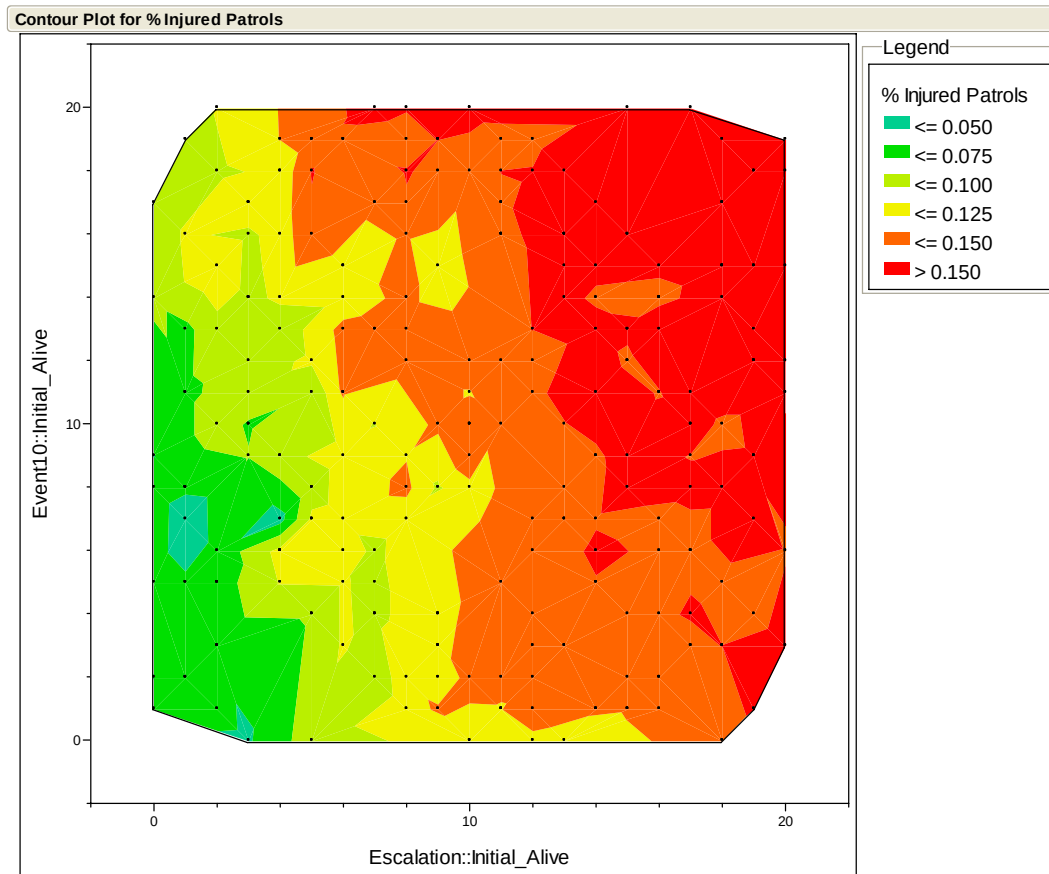


Figure 54. Division Scenario Contour Plot for % Injured Patrols (Force Protection Risk)

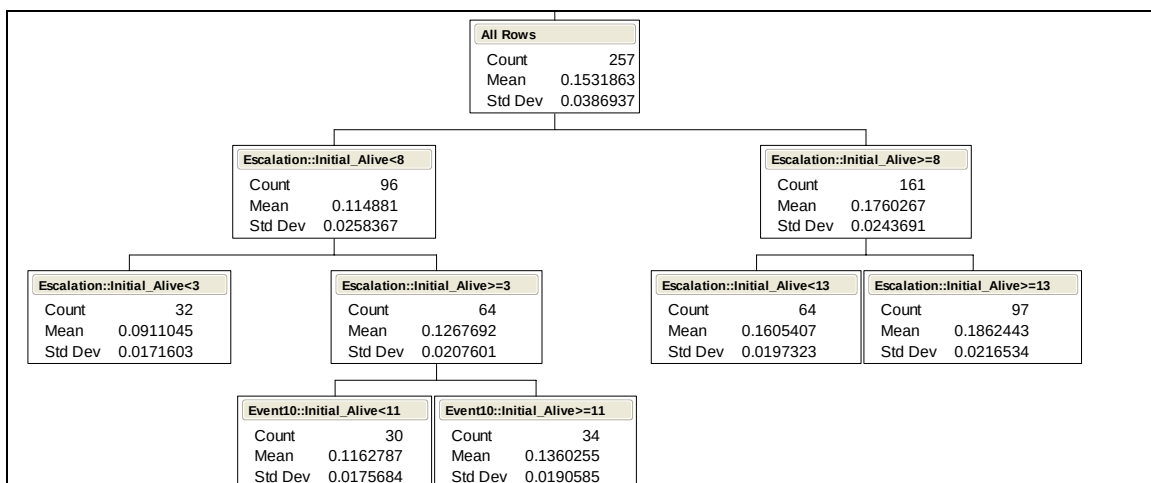


Figure 55. Brigade Scenario Regression Tree Showing Four Partitions of Data for % Injured Patrol (Force Protection Risk)

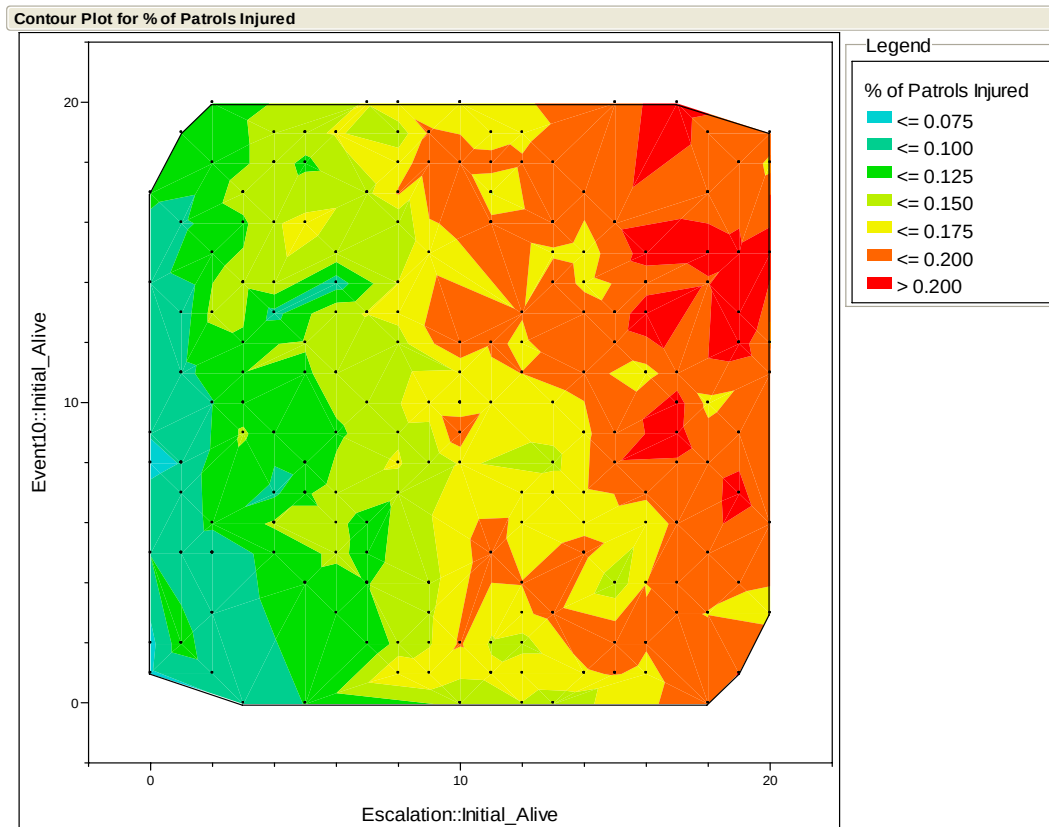


Figure 56. Brigade Scenario Contour Plot for % Injured Patrols (Force Protection Risk)

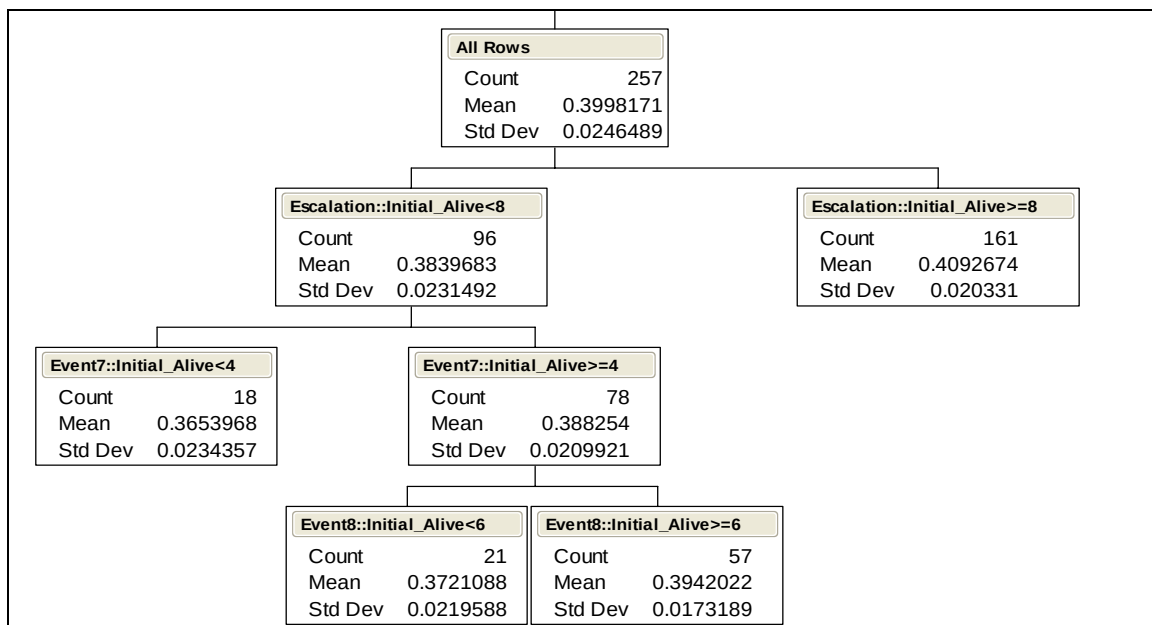


Figure 57. Brigade (-) Scenario Regression Tree Showing Three Partitions of Data for % Injured Patrol (Force Protection Risk)

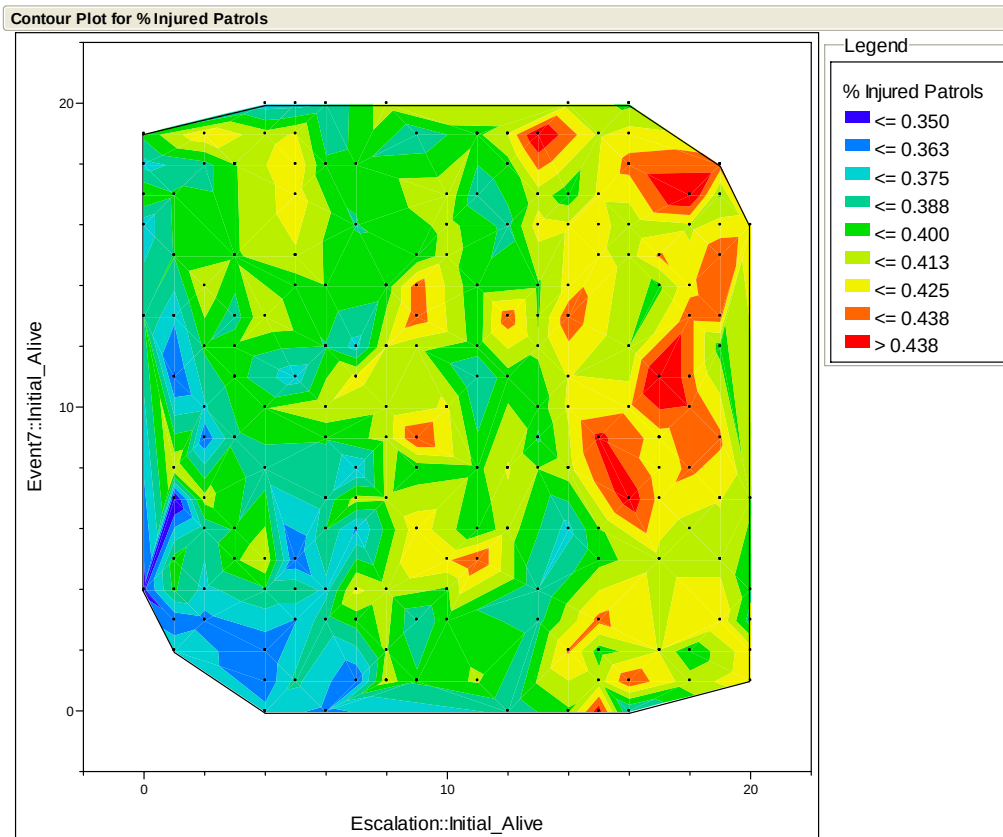


Figure 58. Brigade (–) Scenario Contour Plot for % Injured Patrols (Force Protection Risk)

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APPENDIX D. TRADE-SPACE DATA

The following table shows the data used in identifying the trade-space. It is the result of running all three force size scenarios for 2- , 4- , 6- , 8- , and 10-day durations. Each scenario faced all ten threat levels in the threat continuum. The first three columns show the data used in the Mission Failure Risk MOE. The percentage of mission success is the actual area coverage achieved by the blue force. The higher the area coverage, the lower the risk of mission failure. The last six columns show the data used in the analysis of force protection risk. Two MOPs (% Injured Patrols and Average Patrol Attribute) were used in the analysis of force protection risk. In both cases, the higher the value, the greater the risk of casualties to the force.

Threat Levels		Area Coverage (1 - Mission Failure Risk)			Force Protection Risk			Force Protection Risk		
		% of Red Agents Killed			% of Patrols Injured			Average Patrol Attribute		
		DIVISION	BRIGADE	BRIGADE(-)	DIVISION	BRIGADE	BRIGADE(-)	DIVISION	BRIGADE	BRIGADE(-)
1	2 Days	62.72%	43.41%	30.46%	34.44%	20.43%	68.69%	30.62	15.89	81.37
2		57.82%	40.10%	30.12%	36.39%	22.24%	67.23%	36.66	19.63	87.82
3		53.34%	40.02%	28.68%	37.38%	25.83%	65.66%	41.71	24.77	99.04
4		49.70%	38.51%	27.80%	38.62%	26.79%	68.60%	47.73	27.14	111.95
5		47.21%	37.50%	26.65%	38.44%	29.05%	66.77%	51.52	33.68	118.80
6		44.56%	35.88%	26.23%	38.79%	30.95%	67.54%	55.74	36.04	129.76
7		43.41%	34.72%	25.56%	39.67%	31.97%	66.74%	58.85	39.55	133.36
8		41.26%	33.01%	24.31%	39.86%	31.98%	67.20%	63.35	41.97	145.59
9		39.45%	31.87%	23.33%	40.51%	33.41%	67.51%	67.15	43.68	152.79
10		37.82%	30.68%	23.53%	40.32%	35.41%	66.63%	69.68	46.87	158.96
1	4 Days	91.64%	54.96%	51.10%	15.64%	11.13%	58.54%	51.99	26.61	105.31
2		87.94%	51.84%	48.48%	21.35%	13.33%	61.06%	64.69	33.00	113.82
3		82.35%	51.51%	46.43%	22.60%	15.78%	60.63%	76.64	39.83	125.73
4		78.40%	49.63%	45.10%	26.37%	19.63%	59.89%	89.66	45.82	141.38
5		73.27%	48.37%	43.25%	26.50%	22.59%	59.20%	97.04	55.33	152.07
6		69.39%	46.52%	41.95%	27.40%	22.40%	61.14%	105.38	60.49	161.44
7		66.36%	45.93%	40.72%	28.50%	24.97%	60.09%	111.83	65.80	165.49
8		62.77%	43.61%	39.67%	27.35%	27.27%	61.03%	116.34	71.83	178.76
9		59.70%	42.15%	37.71%	26.01%	28.05%	60.26%	123.06	76.48	185.86
10		56.83%	40.75%	36.96%	24.88%	27.68%	60.11%	126.97	81.82	191.64
1	6 Days	97.98%	60.62%	61.91%	3.45%	6.92%	49.77%	58.28	34.00	117.13
2		95.75%	57.04%	58.63%	6.07%	9.27%	50.51%	74.85	43.00	129.19
3		92.33%	55.66%	56.66%	8.40%	10.43%	49.66%	89.97	50.19	141.71
4		89.73%	54.34%	55.29%	10.06%	13.16%	52.03%	107.17	59.48	159.31
5		86.33%	52.82%	53.56%	9.87%	16.87%	52.49%	118.54	71.14	170.66
6		82.55%	51.26%	51.83%	12.15%	17.10%	50.17%	128.62	78.62	179.00
7		79.09%	50.75%	50.78%	12.01%	19.14%	47.40%	136.07	85.60	182.87
8		75.44%	48.78%	49.39%	13.99%	19.86%	51.63%	143.35	93.35	197.12
9		72.43%	46.87%	47.74%	13.60%	19.17%	48.77%	149.96	99.34	203.29
10		69.10%	45.26%	46.35%	14.55%	20.08%	48.83%	154.38	106.22	210.11
1	8 Days	98.91%	65.07%	68.26%	1.50%	6.38%	43.29%	59.80	40.09	125.04
2		97.74%	60.31%	65.45%	2.99%	7.81%	42.71%	78.79	50.68	137.06
3		95.28%	58.34%	63.36%	5.24%	9.02%	42.89%	96.26	59.30	148.99
4		94.51%	56.58%	62.21%	6.33%	12.02%	45.20%	115.07	69.71	168.96
5		91.66%	56.33%	60.48%	7.45%	13.48%	46.35%	127.58	83.23	180.37
6		88.70%	53.74%	58.53%	9.02%	13.83%	43.43%	139.27	92.61	189.77
7		85.78%	52.50%	57.22%	9.82%	15.67%	42.80%	147.54	99.62	191.98
8		83.12%	50.73%	56.46%	11.35%	16.14%	45.91%	154.93	109.53	206.98
9		80.53%	48.91%	54.82%	11.90%	17.22%	44.23%	161.36	115.98	211.68
10		77.17%	48.55%	52.94%	12.99%	16.90%	44.17%	165.68	125.47	218.33
1	10 Days	99.14%	69.27%	72.51%	1.43%	5.14%	38.80%	60.70	45.19	129.94
2		98.42%	64.23%	69.59%	2.67%	7.40%	39.34%	81.36	57.74	142.04
3		96.59%	61.67%	67.80%	4.61%	8.13%	39.40%	99.97	67.08	154.61
4		96.06%	59.31%	66.63%	6.10%	10.08%	40.63%	119.45	78.56	174.17
5		93.86%	58.72%	65.16%	6.90%	11.89%	42.42%	132.75	92.67	186.27
6		91.28%	56.16%	63.46%	8.54%	12.40%	40.43%	145.24	103.31	195.92
7		88.99%	54.99%	61.60%	9.02%	13.51%	38.40%	153.50	111.19	197.81
8		86.80%	53.24%	61.55%	9.27%	15.19%	42.54%	160.99	122.81	212.09
9		85.41%	51.28%	59.49%	10.92%	14.79%	41.89%	166.83	128.68	216.70
10		82.33%	51.27%	57.88%	12.21%	16.02%	41.91%	171.02	140.82	223.12

APPENDIX E. LESSONS LEARNED FROM BOSNIA

The following paragraphs are excerpts from SFOR Lessons Learned.⁸⁰ They are included because they are viewed as important ideas that should be reinforced when analyzing the trade-space balance between achieving the right presence and force protection risk.

Issue #3: Excessive concern with force protection replaced a focus on mission accomplishment. Soldiers, local nationals, and international community members interviewed repeatedly mentioned excessive concern with force protection as a hindrance to mission accomplishment. This was perhaps the most frequent criticism of SFOR operations. Force protection has become a mind-set, and “no body bags” has become the measure of success. While force protection is undeniably important to maintain political will at home, it should not replace the time-honored principles of security and mission accomplishment.

When the Implementation Force (IFOR) rolled in, the Bosnian public perceived that IFOR had come to clean the place up. IFOR had legitimacy in the public’s eye and could have taken a more assertive posture. However, over time the perception of IFOR/SFOR changed. The local community began to view IFOR/SFOR as a less sincere, less capable, less robust stabilization force. Many locals adopted a “wait and see” attitude and lost interest in cooperating. Similarly, some people mistakenly perceived the U.S. Forces’ mandatory protective gear and multiple vehicle convoys to mean that U.S. Forces were “more afraid” of the locals. This adversely affected how the local community viewed the U.S. Force’s strength and ability to protect the public.

Recommendation: While we should always take prudent force protection measures, this should not come at the expense of mission accomplishment. This is particularly crucial at the start of an operation when the force has the opportunity to define what it will and will not tolerate. Commanders should be aware that a “defining moment” will arise, such as the transfer of the Sarajevo suburbs in early 1996, and the outcome will have enduring consequences for the perceptions of the international presence. Commanders should stay attuned for the defining moments, and be sure their message—the proper message—is the one both sent and received. Mission accomplishment, not force protection, should be the central theme.

Issue #23: Continue to conduct presence patrols and missions. The international community unanimously agreed that SFOR’s most valuable function to date has been the presence of their roving patrols and positioning troops at

⁸⁰ United States Army Peacekeeping Institute, “SFOR Lessons Learned, In Creating a Secure Environment with Respect for the Rule of Law; Based on a Study of Bosnia,” May 2000, pgs. 12 and 34, http://www.au.af.mil/au/awc/awcgate/army-usawc/sfor_rule_of_law.pdf#search=%22SFOR%20Lessons%20Learned%20rule%20of%20law%22. Last accessed on 28 August 2006.

contentious sites at critical times. An SFOR presence not only serves to deter unlawful acts by former warring factions, but it also deters overt violent acts by members of the obstructionist power structures.

The presence of stationary and patrolling troops has proven particularly useful to assist with elections, exhumations (war crime scene investigations), displaced persons and refugees (DPRE) returns, unlawful residents (squatters) evictions, and to allow farmers (of differing ethnicity) to tend their fields. British forces brought the concept of “surge operations” from Northern Ireland and have used this approach effectively in Bosnia.

Recommendation: We should continue to use patrols to assist with missions where SFOR has a supporting role. While this may appear to go without saying, continuing drawdowns have already created tremendous strains on commanders to meet tasks given them. In MND (N), the pullout of certain allied forces coupled with U.S. drawdowns caused one unit to pick up four times the territory for its patrols to cover. It is a physical impossibility to provide the same degree of patrolling efficiency given the resource drain. We need to explore the British “surge operations” concept and consult with key elements of the international community to maximize the use (timing and location) of our troops.

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