SANDIA REPORT
SAND2013-0039
Unlimited Release
Printed January 2013

Report on Project Action Sheet PP05 Task 3 between the U.S. Department of Energy and the Republic of Korea Ministry of Education, Science, and Technology (MEST)

Mark K. Snell

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2013-0039
Unlimited Release
Printed January 2013

Report on Project Action Sheet PP05 Task 3 between the US Department of Energy and the Republic of Korea Ministry of Education, Science, and Technology (MEST)

Mark K. Snell
International Physical Security Department
Sandia National Laboratories
P.O. Box 5800 MS 1135
Albuquerque, New Mexico 87185-MS1135

Abstract

This report documents the results of Task 3 of Project Action Sheet PP05 between the United States Department of Energy (DOE) and the Republic of Korea (ROK) Ministry of Education, Science, and Technology (MEST) for Support with Review of an ROK Risk Evaluation Process. This task was to have Sandia National Laboratories collaborate with the Korea Institute of Nuclear Nonproliferation and Control (KINAC) on several activities concerning how to determine the Probability of Neutralization, P_N, and the Probability of System Effectiveness, P_E, to include: providing descriptions on how combat simulations are used to determine P_N and P_E; comparisons of the strengths and weaknesses of two neutralization models (the Neutralization.xls spreadsheet model versus the Brief Adversary Threat-Loss Estimator (BATLE) software); and demonstrating how computer simulations can be used to determine P_N. Note that the computer simulation used for the demonstration was the Scenario Toolkit And Generation Environment (STAGE) simulation, which is a stand-alone synthetic tactical simulation sold by Presagis Canada Incorporated. The demonstration is provided in a separate Audio Video Interleave (.AVI) file.

CONTENTS

1 Introduction 9

2 Theoretical Background 10
  2.1 System Effectiveness 10
    2.1.1 The Probability of Interruption P_I 10
    2.1.2 The Probability of System Effectiveness, P_E 12
  2.2 Neutralization Analysis 13

3 How Combat Simulations are used to Determine P_N and P_E 17
  3.1 Range of Neutralization Analysis Methods 17
  3.2 Methodology for Using Combat/Complex Computer Simulations to Calculate P_N or P_E 21

4 Comparison of Strengths and Weaknesses of the ITC Neutralization Excel Spreadsheet and the BATLE Software 24
  4.1 Background on the ITC Neutralization Excel Spreadsheet 24
  4.2 Comparison of the ITC Neutralization Excel Spreadsheet versus the BATLE Software 25

5 Demonstration of How a Computer Simulation can be used to Determine P_N. 29

6 Summary 31

FIGURES

Figure 1 - Adversary Task Time vs. PPS Time Requirements 11

Figure 2 - Adversary Planning Preferences along a Path 11

Figure 3 - Probability of Casualty vs. Range 14

Figure 4 - Curve-Fit Equation of Probability of Neutralization Based on the Ratio of Armed Guards versus the Number of Attackers/Threats When Both Have Semi-automatic Rifles (SARs) 18

Figure 5 - Curve-Fit Equation of Probability of Neutralization Based on the Ratio of Armed Guards versus the Number of Attackers/Threats when the Guards Have Handguns While the Attacker/Threats Have Semi-automatic Rifles 18

Figure 6 - Relative Cost of P_N Methods 20

Figure 7 – Relative P_N Accuracy for Different Neutralization Methods 20

Figure 8 - Neutralization Analysis Menu for Neutralization.xls Spreadsheet 24

Figure 9 – Screen Shots from Scenarios Run in STAGE Computer Simulation Software 30

TABLES

Table 1 - Threat Characteristics Data 14

Table 2 - Response Force Characteristics Data 15

Table 3 - Factors Affecting P_N 16

Table 4 - Probability of Neutralization Assuming All Response Forces Arrive at One Time and Both Sides Are Equally Matched in Terms of Weapons, Training, and Other Factors 19

Table 5 - Relative Strengths or P_N Methods 21

Table 6 - Comparison of the ITC Neutralization Spreadsheet Neutralization.xls and the BATLE Software 26

Table 7 - Factors Used in Complex Computer Simulations versus Those Used in BATLE (Marked with "**") 28

NOMENCLATURE

AVI	Audio Video Interleave
BATLE	Brief Threat-Loss Estimator
CDP	Critical Detection Point
CTMC	Continuous Time Markov Chain
DOE	Department of Energy
FAR	Fully Automatic Rifle
FOF	Force-on-Force
HG	Handgun
HMG	Heavy Machine Gun
IAEA	International Atomic Energy Agency
IED	Improvised Explosive Device
ITC	International Training Course
JCATS	Joint Conflict and Tactical Simulation
KINAC	Korea Institute of Nuclear Nonproliferation and Control
LAW	Light Antitank Weapon
LMG	Light Machine Gun
MEST	Ministry of Education, Science and Technology
MVP	Most Vulnerable Path
N	Number of Engagements
P_D	Probability of Detection
P_E	Probability of System Effectiveness
P_H	Probability of Hit
P_I	Probability of Interruption
P_K	Probability of Kill
P_N	Probability of Neutralization
PPS	Physical Protection System
PRT	PPS Response Time
R_N	Number of Response Force Wins in N engagements/N
ROK	Republic of Korea
SAR	Semi-Automatic Rifle
SG	Shot Gun
SMG	Submachine Gun
SNP	Sniper Rifle
STAGE	Scenario Toolkit and Generation Environment
SWAT	Special Weapon and Tactic (Team)

1 INTRODUCTION

This report documents the results of Task 3 of Project Action Sheet PP05 between the United States Department of Energy (DOE) and the Republic of Korea (ROK) Ministry of Education, Science, and Technology (MEST) for Support with Review of an ROK Risk Evaluation Process. Task 3 involves collaborating with the Korea Institute of Nuclear Nonproliferation and Control (KINAC) on methods to determine Probability of Neutralization (P_N) and Probability of System Effectiveness (P_E). The activities under this task include:

- Providing descriptions on how combat simulations are used to determine P_N and P_E;
- Comparisons of the strengths and weaknesses of different neutralization models, Neutralization.xls, and the Brief Adversary Threat-Loss Estimator (BATLE); and
- Demonstrations of how computer simulations can be used to determine P_N.

This task will be covered as a separate report from the report covering tasks 1 and 2.

2 THEORETICAL BACKGROUND

2.1 System Effectiveness

For a physical protection system (PPS) to be effective against theft and sabotage, the response force must both interrupt and neutralize the adversary. Interruption means the response force deploys before the adversary mission is complete and in adequate numbers that the adversary must interrupt the mission and engage the response force in a battle. Neutralization means that the response force stops or permanently interrupts the adversary, who either surrenders, attempts to flee, is captured, or is killed. Both interruption and neutralization must occur for the PPS to be effective.

2.1.1 The Probability of Interruption P_I

The Probability of Interruption P_I is defined based on the Principle of Timely Detection and a Critical Detection Point (CDP). For any adversary path, the P_I is the cumulative probability of detection along the path up to and including the CDP. The CDP is the last PPS sensing opportunity along that path for which the PPS Response Time is less than the remaining adversary Task Time to complete the attack.

P_I is calculated based on two timelines, the adversary timeline and the PPS Response timeline. Figure 1below depicts the adversary timeline at the top, indicating the Task Time it takes the adversary to complete his activities on the path, and also the sensing opportunities along the path that may cause the adversary to be detected. Below the adversary timeline there is a comparison between the PPS Response Time (PRT) and the Adversary Task Time Remaining on the path after first sensing at each possible sensing opportunity.

If the PRT is less than the "Adversary Task Time Remaining After First Sensing," then the corresponding sensing opportunity is considered timely; if this is not the case, then the opportunity is not timely.[1] This is equivalent to the probability that the adversary is detected at a timely sensing opportunity. For the example in Figure 1, the first two sensing opportunities are timely, so P_I = P(Detection at Sensing Opportunity 1 or Sensing Opportunity 2). The Critical Detection Point or CDP is the last sensing opportunity on the path that is timely, in this case Sensing Opportunity 2.

1 This model is called "timely detection" and not "timely sensing" because the timing for the beginning of the detection process is the sensing event; hence, from a timeline perspective timely detection equates to timely sensing.

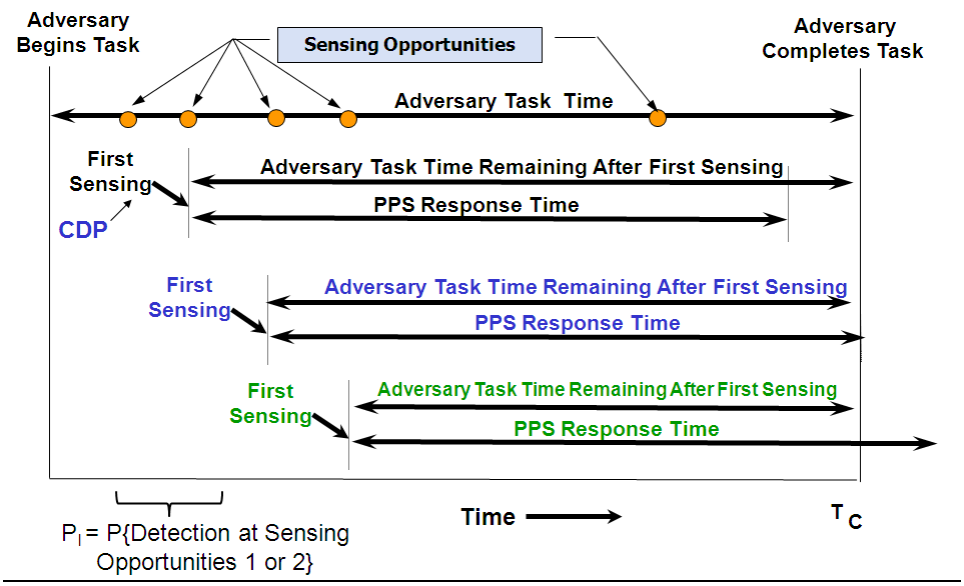

Figure 1 - Adversary Task Time vs. PPS Time Requirements

From the adversary's perspective, their best path would have the lowest Probability of Interruption over all paths through the facility. Such a path achieving the lowest P_I is called the Most-Vulnerable Path or MVP. To determine the MVP, the adversary will start at the end of the path, minimizing delay over elements and strategies at these elements until a CDP is located; then probability of detection is minimized starting at the CDP and moving toward the start of the path; see Figure 2 below. Note that P_I is usually calculated as a numerical value using a mathematical algorithm.

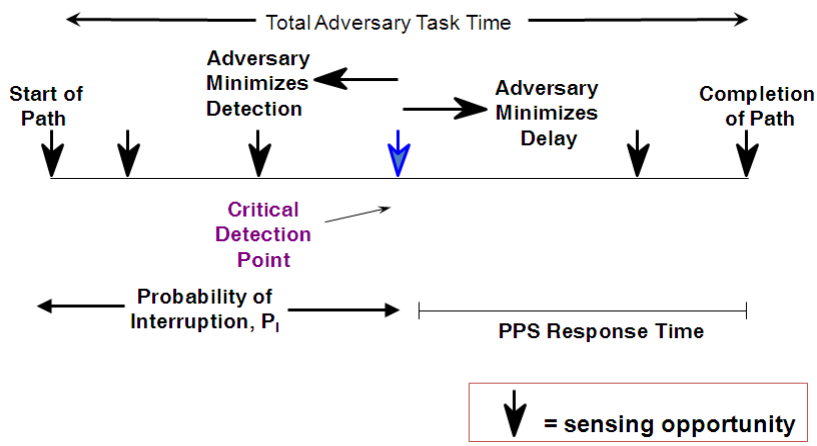

Figure 2 - Adversary Planning Preferences along a Path

2.1.2 The Probability of Neutralization, P_N

The Probability of Neutralization, P_N, is the probability, given interruption of the adversary by the response force, that the response force will gain complete physical control of the adversary force.

Before attempting to describe P_N in more detail, some terms must be defined. An engagement is defined as an event where two opposing forces, such as the response force and an adversary force, use

weapons, tactics, and equipment in an attempt to achieve their respective goals. A win by the response force is defined as the outcome of an attack on a facility, when adversaries defined in the threat are not able to complete a malevolent act successfully. The outcome of a response force win could include: the adversary force is killed, captured, abandons the attack and flees, or no longer has the capability to continue the attack.

We can imagine, conceptually, performing a large number of such engagements (N) during each of which the adversary was interrupted. We will assume that each engagement is performed under the same starting conditions and assumptions and without the adversary or defender learning from any other engagement. Then the Probability of Neutralization is defined as the limit, as the number of engagements, N, becomes very large, of the ratio, R_N:

R_N = Number of Response Force Wins in N engagements/N

We can think of each engagement as a potentially proceeding in a seemingly random way and evolving in different ways. Under some very general assumptions about the individual engagements, when N becomes very large the difference between R_N and P_N grows to be arbitrarily small.

A wide range of models and tools are available to estimate P_N. These include expert opinion, simple calculations, complex simulations, and force-on-force exercises. They differ in the number of variables that are considered and thus in the fidelity of the model to an actual adversary and response engagement. The basic tradeoff in the use of these models is accuracy versus cost.

Because this report focuses on P_N, more is provided on estimating P_N starting in Section 2.2, Neutralization Analysis.

2.1.3 The Probability of System Effectiveness, P_E

The system effectiveness P_E along a path is defined as the product of the two probabilities, P_I and P_N.

$$P_E = P_I * P_N$$

As part of a vulnerability assessment, the overall PPS effectiveness is conservatively defined as the lowest P_E for all adversary paths. This is equivalent to the statement that a chain is only as strong as its weakest link. In principle, this P_E could be determined for all paths, but it is typically difficult to consider more than a few dozen paths.

It is important to note that as calculated, P_I is the same whether all timely detection is placed at the first sensing opportunity on the path or at the Critical Detection Point. For this reason, typically simulations and exercises should be started assuming detection at the Critical Detection Point. Note that this assumption is revisited later in this document.

2.2 Neutralization Analysis

The PPS at a nuclear facility consists of detection, delay, and response functions.

- For sensors, the measure of effectiveness is the probability of detection.
- For barriers, the measure of effectiveness is the delay time.
- For response, the measure is probability of neutralization.

The determination of the probability of neutralization requires information about the response forces, the threat, and the PPS, as well as the choice of a methodology.

Before attempting to determine the effectiveness of a response force in neutralizing an adversary force, some terms must be defined. An engagement is defined as an event where two opposing forces, such as the response force and an adversary force, use weapons, tactics, and equipment in an attempt to achieve their respective goals. A win by the response force is defined as the outcome of an attack on a facility when adversaries defined in the threat are not able to complete a malevolent act successfully. The outcome of a response force win could include: the adversary force is killed, captured, abandons the attack and flees, or no longer has the capability to continue the attack.

Probability is defined as the chance that a given event will have a certain outcome. More precisely, if there exists a number *n* of equally likely possible outcomes to an event, of which a number *s* of these outcomes are regarded as favorable, then the probability of a favorable outcome is given by the ratio *s*/*n*. If the event under consideration is an engagement, then the favorable outcome is a win.

In light of the above, probability of neutralization is now easily defined by the following equation:

$$P_N = N(\text{wins}) / N(\text{engagements})$$

There are two types of processes used to determine the outcome of an event: *deterministic* processes and *stochastic* processes. A deterministic process is one in which results or outcomes are causally determined either by preceding events or by natural laws. When an event is governed by a deterministic process, the outcome needs to be calculated only once, because given the same initial conditions, the event will always have the same outcome. As an example, if a response force member in a vehicle drives from point A to point B at a rate of *r*, and the distance between the points is *d*, the time it takes is equal to *d*/*r*.

A stochastic process is one in which the outcome is determined by random variables. As an example, when a weapon is fired at a target, data can be gathered regarding the number of times the target is hit given a shot, and the results compiled into a probability of hit given a shot. The outcome of each single shot during an engagement can be determined using a stochastic process. Another example of a random variable in an engagement is the probability of casualty given a hit attributed to a specific event. Figure 3 illustrates for comparison purposes the probability of a casualty versus range for a generic handgun (HG) and a generic semi-automatic rifle (SAR).

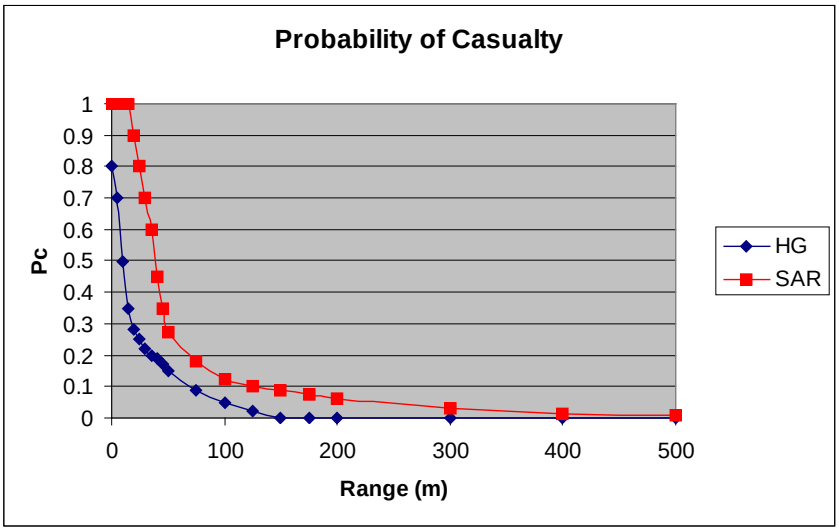

Figure 3 - Probability of Casualty vs. Range

Neutralization analysis requires data on the threat. Threat data includes threat type and numbers, targets, goals, attack scenario, and other information gathered during the Threat Definition process. Information about the threat necessary for P_N analysis is summarized in Table 1.

Table 1 - Threat Characteristics Data

Target	Special tactics
Strategy	Stealth or Deceit
Type	Ambush
Number of attackers	Diversion
Weapons	Body armor
Transport	Communications
Training	Path delay in
Equipment	Target task time
	Path delay out

Similar information is required about the response forces to determine P_N. In addition to response force characteristics data, listed in Table 2, the Rules of Engagement and Order of Battle for each target must be known. The response force characteristics data contains information about weapons, strategies, numbers of guards, transport, response times, etc., for each target.

Table 2 - Response Force Characteristics Data

Strategy	Body armor
Guard types	Communications
Numbers	Response times: – alarm communication – assessment – deployment order – preparation – travel – deployment
Weapons	
Locations	
Transport	
Tactics	
Training	
Equipment	

Rules of Engagement include the conditions and procedures under which various elements of the response force must operate, including when the use of deadly force might be authorized. Examples include:

- Engage at will,
- Engage on command,
- Engage on necessity, and
- Coordinated engagement.

The strategies used by a response force could include:

- Denial – defined as preventing a threat from completing an act such as sabotage, which may require interrupting and neutralizing adversaries before they gain access to a target area.
- Containment,
- Pursuit, and
- Recapture/recovery.

Each strategy should have an objective, which may include:

- Observation,
- Delay,
- Interruption,
- Neutralization,
- Arrest, and
- Backup

A strategy is implemented through the use of tactics. Tactics are very dependent on the facility, competent authority regulations, and the organization that trains and controls the response. Tactics can include:

- Engage at will,
- Engage on command,
- Engage on necessity, and
- Coordinated engagement.

Finally, there are the techniques that the response uses with each tactic-strategy combination. Techniques may include, in increasing order of force:

- Verbal command
- Non-lethal force
- Deadly force
- Other

Table 3 provides some examples of factors affecting PN.

Table 3 - Factors Affecting P_N

Factors	Examples
Numbers	
Weapons suite	None, baton, HG, SG, SMG, SAR, FAR, LMG, HMG, SNP
Area kill	Mortar, LAW, grenades, mines, IEDs
Ammo limits	Rounds/magazine, number of magazines
Training	None, basic, SWAT, military
Tactics	None, simple, advanced, military
Body armor	None, Level I, Level II, Level III, Level IV
Posture	Stand, kneel, prone
Exposure	0%–100%
Movement	Stopped, very slow, slow, medium, fast, very fast, riding
Vehicles	Soft, armored, with weapon
Range	

Note: HG = hand gun; SG = shot gun; SMG = submachine gun; SAR = semi-automatic rifle; FAR = fully automatic rifle; LMG = light machine gun; HMG = heavy machine gun; SNP = sniper rifle; LAW = light anti-tank weapon; IED = improvised explosive device; SWAT = special weapon and tactic (team).

3 HOW COMBAT SIMULATIONS ARE USED TO DETERMINE P_N AND P_E

This section will first discuss the range of models, simulations, and exercises that can be used to determine P_N or to estimate P_E directly. It then moves onto the issue raised by the title to this section, namely, how does one use combat simulations (or complex computer simulations as they are called in this section) to determine P_N or P_E.

3.1 Range of Neutralization Analysis Methods

Several methods for determining probability of neutralization (P_N) include:

- expert judgment (opinion),
- simple numerical calculations,
- complex numerical simulations (computerized war games),
- physical engagement exercises (force-on-force), and
- actual engagements.

Each category has its advantages and disadvantages, primarily in terms of time, cost, and accuracy.

Expert judgment is the opinion of one or more subject matter experts about the effectiveness of the response forces. This opinion must be tempered by the background and experience of the expert, knowledge of the response forces at the facility, and knowledge of the threat. Expert judgment is difficult to verify, and, unless the same expert is involved in all of the estimations, results can vary from site to site and even target to target. Further, if two or more experts disagree, there is no way to tell if the P_N is valid.

Tabletop (or sand table or military map) analysis involves using a map or site schematic with either icons or figurines to represent combat elements. This method has been used in warfare at least since Roman Legion times, and probably earlier. Commanders can place the icons in various positions on the map and debate the outcome of possible engagements. A crucial element for tabletop analysis is the method used to determine the outcome of engagements. Expert judgment, data tables, or a set of rules with simple numerical calculations are the most common methods.

Simple numerical calculations are often used in place of, or to augment, expert judgment determinations. Simple numerical calculations include data tables, curve-fitted equations, Continuous-Time Markov Chain (CTMC) methods, and Monte Carlo methods. The following two figures (Figure 4 and Figure 5) present a comparison of a curve-fit equation used in the Neutralization.xls model included in the International Atomic Energy Agency's (IAEA's) courses in Physical Protection compared with the results of a more complex Continuous Time Markov Chain model found in the Brief Adversary Threat-Loss Estimator. Both of these two tools are compared in more detail in Section 4.

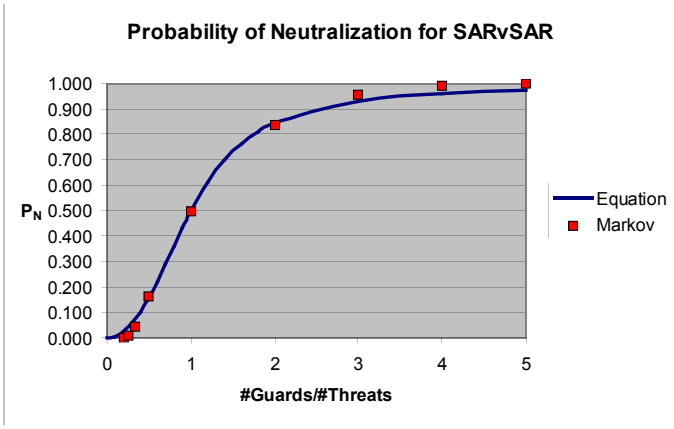

Figure 4 - Curve-Fit Equation of Probability of Neutralization Based on the Ratio of Armed Guards versus the Number of Attackers/Threats When Both Have Semi-automatic Rifles (SARs)

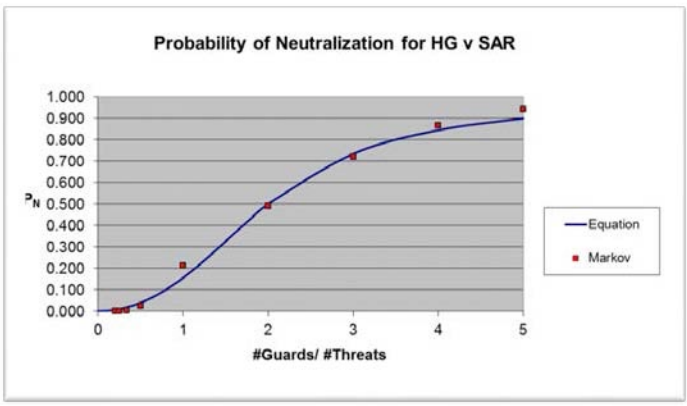

Figure 5 - Curve-Fit Equation of Probability of Neutralization Based on the Ratio of Armed Guards versus the Number of Attackers/Threats when the Guards Have Handguns While the Attacker/Threats Have Semi-automatic Rifles

Note: Figure 4 plots Probability of Neutralization when the (armed) guards and adversary/threat have semi-automatic rifles (SAR) while Figure 5 plots Probability of Neutralization when the (armed) guards have handguns (HG) and the attackers/threats have semi-automatic rifles (SAR).

A very rough estimate method for calculating P_N basically uses a table (see Table 4 below), which compares the number of response force members to the number of adversaries. In this case, the capabilities of the response force and adversaries were assumed to be the same, other than their numbers.

Table 4 - Probability of Neutralization Assuming All Response Forces Arrive at One Time and Both Sides Are Equally Matched in Terms of Weapons, Training, and Other Factors

Number of Response Force Members	Number of Adversaries: 1	2	3	4	5	6
1	0.500	0.165	0.042	0.007	0.001	0.000
2	0.835	0.500	0.225	0.079	0.024	0.006
3	0.958	0.775	0.500	0.260	0.112	0.040
4	0.993	0.921	0.740	0.500	0.285	0.139
5	0.999	0.976	0.888	0.715	0.500	0.303
6	1.000	0.994	0.960	0.861	0.697	0.500
7	1.000	0.999	0.987	0.943	0.839	0.683
8	1.000	1.000	0.996	0.978	0.926	0.821
9	1.000	1.000	0.999	0.993	0.968	0.910
10	1.000	1.000	1.000	0.998	0.988	0.958
11	1.000	1.000	1.000	1.000	0.996	0.982
12	1.000	1.000	1.000	1.000	1.000	0.993
13	1.000	1.000	1.000	1.000	1.000	0.998
14	1.000	1.000	1.000	1.000	1.000	1.000
15	1.000	1.000	1.000	1.000	1.000	1.000
16	1.000	1.000	1.000	1.000	1.000	1.000
17	1.000	1.000	1.000	1.000	1.000	1.000
18	1.000	1.000	1.000	1.000	1.000	1.000
19	1.000	1.000	1.000	1.000	1.000	1.000

Computerized engagement simulations are a third category of Neutralization Analysis. The Joint Conflict and Tactical Simulation (JCATS) is one example. JCATS is a multi-user computer simulation developed for analysis of large-scale force-on-force engagements. JCATS was adapted from a U.S. Army application by one of the U.S. Department of Energy (DOE) national laboratories for use in doctrinal planning. JCATS evolved from the original military map and tabletop exercises, but is more sophisticated. JCATS requires a minimum of two highly trained users and significant setup time. The simulation also requires at least three networked computers, one for threat, one for response, and one for administrative control.

The simulation contains large databases for weapons, equipment, and individual combatant performance, including operations on varied terrain and day/night conditions. The tool also requires that data for the actual environment, terrain, and structures are input into a terrain editor. JCATS also requires at least two real-time war-gamers to operate the system and simulate the engagement, and one specialist to design the battlefield and activate the appropriate numerical combatants. The results have been shown to be "operator and player-dependent," i.e., a skilled computer game player can sometimes defeat more able military tacticians and thus skew the results.

Another example is a modeling and simulation tool known as the "Scenario Toolkit And Generation Environment (STAGE). STAGE is a stand-alone synthetic tactical simulation, sold by Presagis Canada Inc.,

which provides solution visualization and can be run in the batch mode using one operator so it is less manpower-intensive than JCATS.

Simulated physical engagements are also known as force-on-force (FOF) exercises. FOF exercises are not actually evaluation methodologies but should be considered training exercises or validation exercises. At a real facility, FOF requires four groups: mock adversaries, mock responders, referees, and the on-duty response force personnel. These exercises are expensive in terms of both personnel and planning, are usually run only a few times at a facility, and can also produce skewed results. Statistically, there are usually not enough engagements to produce a probability of system win with a high confidence level. For example, if only one exercise is completed and the response forces lose, does this mean that the response force probability of neutralization is zero? Probably not!

Actual engagements have one big advantage: the outcome is a known fact. Obviously, comparison of actual engagements results with either live fire or simulation exercises can be complex and costly; however, such comparisons prove the validity of simulation techniques. Comparisons of these five general methods in terms of cost and accuracy are shown qualitatively in Figure 6 and Figure 7.

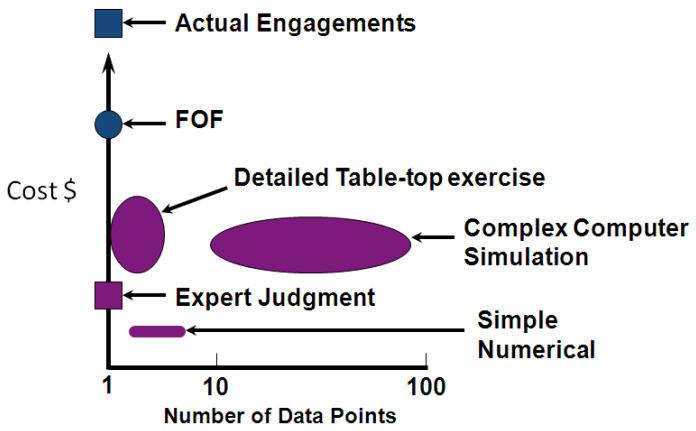

Figure 6 - Relative Cost of P_N Methods.

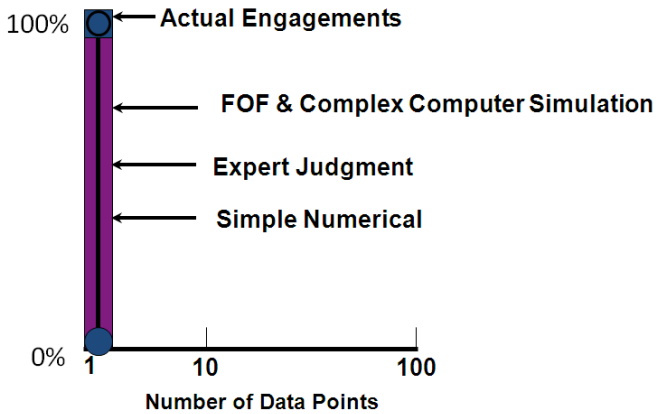

Figure 7 – Relative P_N Accuracy for Different Neutralization Methods

Figure 7 can be interpreted in a misleading way because it suggests that complex computer simulations, FOF, and actual battles have the highest precisions. Further, since dozens of data points can be collected from complex computer simulations, this would seem to be the best approach of the three to take. Actually, each approach has relative strengths and weaknesses, and computer simulations are no exception (see Table 5 below). As seen in Table 5, FOF exercises are good at replicating tactical behaviors by individuals, while complex computer simulations are good at producing all munitions effects and creating a comprehensive history of events. Detailed tabletop exercises can be performed in such a way that they explore group decision making by both the adversary leader and the security leader since this is either helped or hurt by security plans.

Table 5 - Relative Strengths or P_N Methods

Force-on-Force (FOF)	Computer Simulation	Detailed Tabletops
Good at replicating individuals <u>behaviors</u> ▪ Individual and team tactics	**Good at replicating <u>events</u>** ▪ Munitions effects	**Good at replicating <u>decision-making</u>** ▪ Security/adversary commanders ▪ Completeness of plans
More required tasks actually executed ▪ Murphy's law	**Comprehensive view and record of events** ▪ Engagements ▪ Movement	**Transparency of observers** ▪ Event handling ▪ Technical decisions
More fidelity in representing actual site: ▪ Terrain fidelity ▪ Actual responders	**Flexibility of application:** ▪ Any attack location/situation ▪ Can run multiple iterations to develop statistical data ▪ Less impact on operations	**When lead by an expert exercise moderator tabletops can:** ▪ Identify issues to be addressed by other simulations ▪ Bring in stakeholders as supporters that the simulation was done correctly

3.2 Methodology for Using Combat/Complex Computer Simulations to Calculate P_N or P_E

Once the appropriate data are collected, the neutralization analysis may begin. The first step is to select a methodology. In this section we will assume that a complex computer simulation is used alone to determine P_N or P_E.

There are some important considerations for using such simulations to determine P_N or P_E:

- While P_N or P_E is calculated based on a computer simulation, the simulations themselves have to be validated by actual Force-on-Force exercises before the results of the simulations are used.

- Detailed tabletop exercises should be performed before the combat simulations are performed to determine if the proposed scenario(s) to run in the simulations are valid and the response behavior will be consistent with response/security plans.

Thus, even when P_N or P_E is calculated using one of the tools, i.e., computer simulations; the other two detailed approaches, namely tabletop exercises and FOF, should also be used.

To support use of computer simulations to determine P_N or P_E, the computer simulation, tabletop exercises, and FOF exercises should be used in a specific sequence, dependent upon whether a country has performed FOF exercises before:

- If the country is performing FOF exercises for the first time, conduct tabletop exercises first, next conduct FOF exercises, and perform computer simulations last. Here the computer simulations are set up to be consistent[2] with the first FOF data collected; and then the computer simulations are run to validate that the results are indeed consistent. After this validation, the computer simulation can be run a number of times to calculate a P_N, versus P_E.
- if FOF exercises have been performed before, conduct tabletop exercises first, next perform combat simulation, and finally conduct FOF exercises. In this case, the FOF exercises serve to validate the outcome of the tabletop exercise and computer simulations. Note that in this case the computer simulations are used to calculate P_N before the FOF; if the FOF validates these results, then that value of P_N is reported. (Note: if the FOF exercise does not validate the tabletop exercises and computer simulation results, then one would have to start this process over and recalculate the P_N value based on the new computer simulation results.)

In either case, calculate P_N = # of wins/# of simulations performed using (complex) computer simulations. Note that it is unusual to report that $P_N = 1.0$, even with the number of wins equal to the number of simulations run. In the case where the number of wins is equal to the number of simulations run, there are a number of Bayesian-like approaches for calculating P_N, such as $P_N = (N+.5)/(N+1)$.

It is also important to consider how the point of initial detection of the adversary can be identified during each computer simulation. Several approaches can be used to select such a point:

1) At the worst case sensing opportunity: assume detection occurs at the Critical Sensing opportunity. This approach is typically used when calculating P_N (as opposed to P_E) based on the simulation;
2) At the most-likely sensing opportunity (that is, cumulative Probability of Detection (P_D) up to some layer meets or exceeds some high probability value P*). This approach can be used for calculating P_N (as opposed to P_E); and
3) At a sensing opportunity chosen randomly between "runs." In this case, assume that a uniform random variable, U, is selected at the beginning of a computer simulation. Then the point of

[2] Typically, consistency checking between a computer simulation and a FOF exercise is relatively informal because only a few FOF exercises can be carried out to compare with relatively more computer simulations. One way to check more carefully for consistency (or to validate computer simulations based on FOF exercises) is to look at quantitative variables, such as the number of combatants killed on both sides, and the times when certain events in the simulation occurred.

initial sensing is chosen to be: at sensing opportunity 1 if $U \leq P_{D1}$, at sensing opportunity 2 if $P_{D1} < U \leq P_{D1} + (1-P_{D1})*P_{D2}$, etc., up to a test for the point of initial sensing to be at the CDP sensing opportunity if

$$1 - \prod_{1}^{CDP-1}\left(1 - P_{Dj}\right) < U \leq 1 - \prod_{1}^{CDP}\left(1 - P_{Dj}\right).$$

This approach is used to calculate P_E directly as the point of detection is chosen randomly between the timely detection points, whereas a P_N calculation must choose the point of detection at either the CDP (approach 1) or at a point where sensing is most likely (approach 2), used when there is low timely detection between this point and the CDP.

Note that the concept behind approach #3 is often used in tabletop exercises, but with the modification that the sensing opportunities are tested one-by-one (that is, the point of initial sensing is tested for sensing opportunity 1 using the rule, "sensing (and assessment) occurs if $U_1 \leq P_{D1}$." if detection does not occur at sensing opportunity 1, then next try sensing opportunity 2, where the test is now based on the rule that initial sensing is at sensing opportunity 2 if $U_2 \leq P_{D2}$ (where U_2 is a new uniform random variable; etc.). In this sense, tabletop exercises typically determine P_E rather than P_N, although approaches 1 and 2 *could* be used during a tabletop exercise.

4 COMPARISON OF STRENGTHS AND WEAKNESSES OF THE ITC NEUTRALIZATION EXCEL SPREADSHEET AND THE BATLE SOFTWARE

4.1 Background on the ITC Neutralization Excel Spreadsheet

This method was developed specifically for use in training in the International Training Course (ITC). The application is a Visual BASIC-based menu-driven estimation tool based in the Microsoft® Excel© application. The method is based on data derived from a Markov chain model where the data table values are adjusted for varying numbers of guards engaging varying numbers of threats with all other engagement parameters except that numbers, weapons, and arrival times are equal. Force-multiplication coefficients are used to account for differences in weapons. An exponential decay function is used to compute the effects on P_N caused when successive response groups in the Order of Battle have varying arrival times. The purpose of this basic technique is to emphasize the three most important factors for the response:

- numbers (one threat group, up to five response groups)
- weapons (none, baton, handguns, rifles)
- arrival times (path delay and response times)

Figure 8 shows the application menu used for entering these factors into the tool.

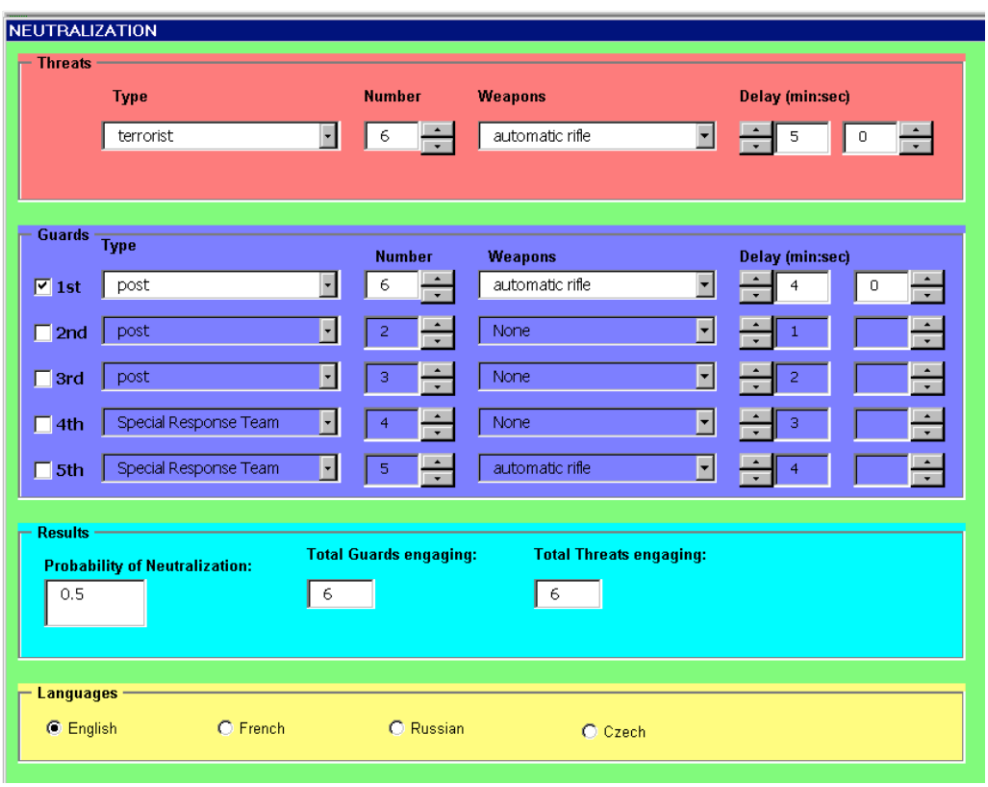

Figure 8 - Neutralization Analysis Menu for Neutralization.xls Spreadsheet

The spreadsheet method is based on a number of assumptions, including the following:

- Superior weapons increase P_N for equal numbers
- Superior numbers increase P_N for equal weapons
- Net effect of superior weapons is force multiplication, where

  $P_N = f\ (E_{Guards}*M_{Guards}, E_{Adversary}*M_{Adversary})$

  M = number of combatants

  E = weapon effectiveness force multiplier
- Rule-of-two weapons effectiveness is used

  for $P_N = 0.50$,

  1 baton = 2 no weapons

  1 handgun = 2 batons

  1 automatic rifle = 2 handguns

The Neutralization.xls code also demonstrates two other effects:

- Response forces are counted in the battle only if they can arrive in time to interrupt given detection at the path Critical Detection Point, and
- Probability of Neutralization increases when response groups arrive closer in time versus longer in time.

4.2 Comparison of the ITC Neutralization Excel Spreadsheet versus the BATLE Software

The most important distinction is that the Neutralization spreadsheet was developed as a training tool expressly for the International Atomic Energy Agency's International Training Course (ITC) in Physical Protection while the BATLE software (implemented in the C software language) was used in the late 1980's and early 1990's as a P_N tool for U.S. vulnerability assessments. Some other distinctions between these codes are shown in Table 6.

Table 6 - Comparison of the ITC Neutralization Spreadsheet Neutralization.xls and the BATLE Software

Aspect of Neutralization Model	Neutralization.xls	BATLE Software
Incorporates Order of Battle	YES	YES
Use of Probability of Hit/Probability of Kill (P_H/P_K) and rate of fire data	NO – arbitrary "rule of 2" between batons, handguns, automatic rifles	YES
Incorporates Range in P_H/P_K and rate of fire in P_N model	NO	YES Range affects both rate of fire and P_H/P_K
Based on Continuous Time Markov Chain	NO – model merely fitted to a limited set of BATLE results	YES – Determines P_N using Runge-Kutta algorithm
Allows user to control for individual combatants such factors as: exposure while firing/not firing (0 to 100%), firing rate, and whether suppressed or not, Posture (standing, kneeling, prone)	NO – adversaries and guards with the same weapon category (batons, handguns, and automatic rifles) are all assumed to have the same exposure, firing rate, suppression, etc.	YES – Each combatant (adversary or Response Force member) can have different settings
Allows user to modify numbers, weapons, and other factors during the engagement	NO – only one set of values	YES – Several "events" can be defined with different assumptions
Incorporates Delay After the Critical Sensing opportunity to keep the adversary in the engagement at least this amount of time	YES – explicit in model	It depends – the versions of BATLE model used in vulnerability assessments allow this while other versions do not

Note that there was some talk about incorporating range in the neutralization spreadsheet at one point but this was never implemented.

BATLE allows up to 10 events per neutralization analysis. During each event, the BATLE software allows the user to set several factors for each individual combatant modeled:

- Combatant exposure while firing (as a percentage);
- Combatant exposure while NOT firing (as a percentage);
- Reloading Time for the weapon;
- Firing delay (as a percentage) that reduces the rate of fire for the weapon below the fastest firing rate for the weapon;
- Posture of the combatant as standing, kneeling, and prone while firing and while reloading;
- Whether one side or the other is suppressed due to high rates of accurate weapons fire from the other (and the length of time suppression lasts can also be set); and
- Whether the combatant is in a defensive stance versus in an attacking stance (the latter tends to increase the exposure of the combatant, other factors being equal.

Table 7 below lists factors that can be set within complex computer models. These factors fall into two main classes:

- Factors that either affect the ability of a combatant to cause a casualty with a certain type of weapon among the forces on the other side of the battle or affect the firing rate for that weapon. Note that, by comparison, the only factor under Probability of Hit/Probability of Kill (P_H/P_K) or firing rate incorporated into the Neutralization.xls is the choice of hand gun versus a semi-automatic rifle by a combatant.
- Factors that affect the exposure of attackers or defender combatants to be hit with weapons fire. Typically, 50% exposure for a combatant means that roughly two times as many rounds must be fired by the other side to incapacitate that combatant as compared to the same combatant 100% exposed. Note that the Neutralization.xls spreadsheet assumes that all combatants have 100% exposure.

Note that in Table 7, the factors annotated with "**" are used in the BATLE code.

There are other factors, such as level of tactical training and use of weapons, that are very important. These other factors are extremely difficult to model, so calculations are performed with the strong assumption that response forces are at least as well trained in moving tactically and in using weapons as the adversary. This way, using the same P_H/P_K curves for the same weapon on both sides is a conservative approach, leading to P_N values, whether determined by BATLE, FOF, tabletop exercises, or computer simulations, that are lower than (or at least equal to) the values that would be achieved if such training factors could be accurately modeled.

In summary, the Neutralization.xls spreadsheet has been used for training and it has not been validated and verified. The BATLE code has been used in the past in the U.S., but now other tools are considered to be better; for example, combat simulation-based P_N or P_E values (based on some combination of detailed tabletop exercises, FOF exercises, and computer simulations) are considered to be superior to BATLE.

Table 7 - Factors Used in Complex Computer Simulations versus Those Used in BATLE (Marked with "")**

Factors	Examples
Factors Influencing Shooter Probability of Hit/Probability of Kill (P_H/P_K) As Well As Firing Rates	
Examples of Direct Fire Weapons**	Hand Gun, Shot gun, Submachine Gun, Semi-Automatic Rifle, Fully Automatic Rifle, Light Machine Gun, Heavy Machine Gun, Sniper Rifle
Examples of Area Kill Weapons	Mortar, Light Antitank Weapon (LAW), grenades, mines, Improvised Explosive Devices (IEDs)
Shooter Movement	Stopped, very slow, slow, medium, fast, very fast, riding
Target Movement	Stopped or moving: very slow, slow, medium, fast, very fast, riding in a vehicle
Range**	Range between shooter and target combatant
Ammo Limits**	Expressed in terms of rounds/magazine and number of magazines; such limits reduce the effective firing rate for the weapon
Shooter Suppression**	Under certain circumstances, the shooter cannot fire back for a period of time because so much weapons fire is directed at him or her. (Note: This effect is called suppression.)
Factors That Influence Combatant Exposure As Targets (Exp)	
Body Armor	None, Level I, Level II, Level III, Level IV: Factored into Exposure, as the percentage of the combatant's body still exposed against the weapon through the body armor
Posture**	Standing, kneeling, lying prone
Exposure**	0%–100% (Note: Some models allow the user to set exposure while firing as a separate value from exposure while not firing.)
Whether the combatant is on foot or in a vehicle	If in a vehicle, there is a chance that everyone in the vehicle could be killed by a hit. This is referred to as a "catastrophic" kill. On foot, each combatant must be individually killed although several may be killed by area kill weapons.
"Soft" Factors Typically Assumed To Be the Same or Better for Response Forces Versus Adversaries	
Training	None, basic, SWAT, military
Tactics	None, simple, advanced, military

5 DEMONSTRATION OF HOW A COMPUTER SIMULATION CAN BE USED TO DETERMINE P_N.

Many combat simulation tools exist. Figure 9 displays two images captured from one of them, STAGE, which provides the user the capability to evaluate tactical engagements and, based on the number of wins, estimate a P_N. These screen shots are recorded from two AVI files, STAGE_DEMO_I.avi and STAGE_DEMO_II.avi, produced from STAGE runs.

Some combat simulations have human operators controlling the entities while others allow users to program adversary and response software behavior models. If properly trained, the human operators provide better results than using software behavior models, but this comes at a cost: the human operators cost much more per simulation and only a few simulations can typically be run per scenario, whereas literally hundreds of combat simulations of a single scenario can be performed using software behavior models. This does not mean that the behavior models give more accurate results; in many cases their results tend to be much more precise (based on dozens or hundreds of runs), but their accuracy may be lower.

To review the discussion in Section 3, countries that had not run FOF exercises in the past should first conduct tabletop exercises to validate response plans, then perform FOF exercises to ensure that response forces are properly trained to conduct those response plans, and finally run computer simulations. These computer simulations would first be validated as consistent with the FOF exercises and only then would the computer simulations be used to calculate P_N; for more details, see Section 3.2, "Methodology for Using Combat/Complex Computer Simulations to Calculate P_N or P_E." If the country had run sufficient numbers of FOF exercises in the past, then the computer simulations could be run first and FOF exercises would be performed afterwards to validate the computer simulation results.

Figure 9 – Screen Shots from Scenarios Run in STAGE Computer Simulation Software

6 SUMMARY

The effectiveness of a PPS can be expressed as the product of two probabilities: P_I and P_N. P_I is determined from "timely detection," and is a measure of the effectiveness of the system detection and delay along a path when compared to a response force time. P_I describes only the cumulative probability that the adversary may be interrupted. This metric alone does not answer the question of who wins—the response force or the adversary. P_N is the measure of effectiveness of the response against the adversary, independent of P_I. Together, the two define the effectiveness of the overall PPS.

This report discussed five methods for determining the probability of neutralization (P_N):

- Expert judgment (opinion),
- Simple numerical calculations,
- Complex numerical simulations (computerized war games),
- Physical engagement exercises (force-on-force), and
- Actual engagements.

Each method has strengths and weaknesses, and provides different insights an analyst can use to estimate P_N. The example used for a training course is a method that uses a Markov Chain analysis technique, put into a simple computer interface, to allow the calculation of $P_{N,}$ used to compute overall system effectiveness. The computer model uses input data about the adversary and defender numbers, weapons, system delay, and response times. The output is an estimate of the probability that the defending force will be successful, or P_N.

DISTRIBUTION

1	MS1361	R. Berry	6833
1	MS1361	S. Ortiz	6833
5	MS1361	M. Snell	6833
1	MS0899	Technical Library	9536 (electronic copy)

Sandia National Laboratories