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Ground Combat Study: Summary of Analysis

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Introduction

In the USMC Ground Combat Study we are focused on small unit (squad and fire team) size and organization. Our goal is to use an analysis of historical changes in squads together with an analytic tool to provide the Marine Corps with an assessment of the relevance of these units on the future battlefield. Using CNA-initiated funding, we plan to demonstrate the utility of analyses in one of the USMC's core warfighting areas. We also plan for this study to be the first in our program of research into ground combat and, at a more general level, MAGTF operations.

This report reviews our results to date and presents a path for future study. As we'll see later in the paper, the focus is on using EINSTein[1] as a tool to analyze small unit actions on the battlefield.

To briefly summarize, we have completed a historical review of small unit sizes and organizations generating a wealth of data to use in our subsequent analyses of small ground combat units. And, at this point, we are satisfied with EINSTein's ability to "get the answer right vis-a-vis this historical record." We'll explain later what we mean by this statement and why we choose EINSTein as our tool. As a result of these favorable results, we recommend continuing our analyses of small unit sizes and organizations using EINSTein as our tool for examining ground combat.

Background

The first question one might ask is, "Why spend time analyzing ground combat?" The answer comes at two levels. The pragmatic answer is that ground combat is one, if not the premiere, of the

1. EINSTein is an entity-based model for exploring ground combat developed at CNA. See reference [1].

USMC's core warfighting areas. For that reason alone, it should be a focus of our analytical effort for the Marine Corps.

At a more basic level, there are a number of interesting analytical issues in ground combat today where CNA could help. Some of these topics include: the impact of new weapons systems; how OMFTS will impact the infantry units; fire support coordination; combat in urban terrain; and the organization of the infantry division.

In this study, we are focusing at the smallest level (the squad and fire team) and looking at how these small units have changed with time and why they've changed. Understanding the drivers of these changes will allow us to analyze the future warfighting environments that the Marine Corps may face, and examine the relevance of various small unit organizations in these future environments.

Tasks

In December 1999, we embarked on the current phase of this analytical effort. Over the last few months, we have focused on determining an analytical path and generating results. Overall, the primary goal for our analysis is to examine the relevance of small units in the future warfighting environments likely to be faced by the Marine Corps.

We designed our answer to this primary question by first focusing on a historical review of the changes in small unit size and organization. From the early 1900s, the Army's (and, to a lesser extent, the Marine Corps') squads have changed a number of times due to a wide range of driving factors (changes in weapons technology, for example). From the wealth of historical data, we've been striving to isolate those changes that could be analytically understood in terms of these underlying drivers.

Combining our understanding of the drivers of changes in the small units with a set of analytical tools, we planned to address the future relevance of these units. Thus, of equal importance to our historical review are: choosing what analytical tools to use as we synthesize our historical data, outlining the future warfighting landscapes likely to be faced by these units in the Marine Corps, and examining the relevance of small units in these future battlefields.

An important objective of this work is to demonstrate to the Marine Corps that analytical thought has a place in the core warfighting areas of the Marine Corps, just as it does in the supporting areas such as manpower or resource analysis.

The tasks we've focused on in this phase of our analysis, documented herein, are:

1. Analyzing the historical record of changes in small unit sizes and organizations. Using this analysis to draw out the drivers of small unit change, and understanding which of these factors have been the most important drivers of change—the factors that must be understood and captured in our subsequent analyses. This task can be thought of as developing the basic data to be used later in our analytical framework.
2. Choosing an analytical tool that we can use to answer our basic question about the future of small ground combat units in the Marine Corps. And, in a validation mode, ensuring that our tool captures the important points from our historical analysis.

While these two tasks are admittedly a subset of our original goal, they have been significant steps forward from an analytical standpoint (getting the model right), and from the standpoint of laying the historical framework in which we hope to answer our basic question about the future relevance of small units in the Marine Corps.

Outline

The next section of our report focuses on our analytical methodology. We discuss how we've begun to use our historical research together with an analytical tool. The third section of this report provides an overview of this historical record and focuses on the most important points, ones that we as analysts need to understand. In section four, we review how we settled on EINSTein as our analytical tool. The next two sections present our analytical path and results. And finally, we conclude with a summary and recommendations for future analyses in this area.

Methodology

We began our analysis knowing that without first reviewing the historical record, and being able to interpret and pull out of that record the important driving factors of change, we would be unable to fully answer our basic question. While this section refers ahead to the next two sections for additional details, we put it here because it captures our initial thinking on an analytical approach, and because it lays the context for understanding how the next two sections fit together and the role they play in reaching the goals of our analysis.

Historical context

Leaving the details for the next section, the historical record, together with all the nuances and drivers of change, provides us with a wealth of data. Understanding these data is the first step in our methodology. By synthesizing this record and determining which factors have been the major drivers of change (for example, technological changes, particularly in weaponry) and understanding how these drivers have influenced squad size and organization, we can then use this understanding to predict the influence of these important drivers on future squads. The assumption here is that these drivers will still be important in the future and that understanding how they have driven squad size and organization in the past is the first step in analyzing what small unit organizations and sizes will be relevant for the Marine Corps in the future.

Analytical models

In addition to our historical review, we examined the range of models available for analyzing ground combat (see section four). Our initial focus in this review was to better understand the relevant drivers of change at the squad level from a modeling standpoint (in other words, to see how others had included these factors in their work).

However, as we moved forward, it became apparent that we would need an analytical tool (e.g., model, simulation, or field test) to answer our basic question. We realized early on that a pen and paper analysis would not be able to capture the multitude of variables that can influence ground combat; we knew we needed a more robust tool.

One of our first observations was that the number of variables required to describe a combat system quickly became quite large. These variables can be divided into tangible and intangible. The tangible variables include weapons parameters, terrain, weather, and force distribution. The intangible variables include the effects of personality, morale, courage, and leadership. As you'll see later, we want to control these intangible factors (they are typically controlled in modeling and field tests) that can influence the outcome of one battle. However, over time it is not the intangible factors that have been the driving factors of the changes in squad and fire team organization; it is a set of tangible factors such as firepower, resilience, and mobility.

As a solution to this challenge of many variables, the existing models focus on combat at a much higher level than the squad. Both deterministic and stochastic models view combat as a conglomeration of many smaller fire fights and solve the multi-variable problem by averaging over large forces. Remember, our goal is to find a tool that we can use at the squad level.

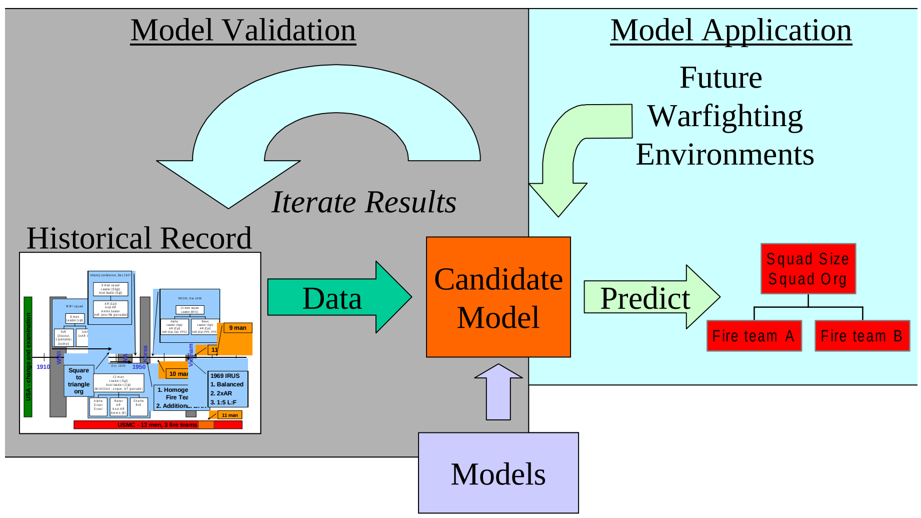
The very nature of our problem focuses us on the individual fire fight, and we cannot jump to the large problem or its solution for refuge. Luckily, recent developments in entity-level simulation models gave us our solution. EINSTein is the first application of an entity-based model (one that considers individual warfighters and not aggregate numbers) to land warfare. EINSTein builds combat from the interactions of individual combatants and groups them together to calculate results.

Our question is, Can we use EINSTein as our tool to analyze squad organizations and sizes?

Synthesis

Figure 1 shows how we are combining our historical analysis together with our analytical tool. Because EINSTein has not been used at the small end of the ground combat spectrum (individual squads and fire teams), we felt that it was necessary to increase our confidence in its ability to work at this level. In essence, we are using the historical record to test EINSTein as a tool for our ground combat analyses. As you can see, we have broken the process up in to two phases.

Figure 1. Analytical methodology



At the left of the figure, we show the process by which we choose and test our analytical model. From the multitude of models and simulations, we decided that EINSTein was our best candidate for use in this analysis. Applying our historical record, we hope to see similar "answers" from the model. In other words, if in a given historical situation, a particular change in technology caused squad organizations to change, we would hope to see a similar effect in our model. By iterating this process over a range of historical (and other well-known) examples, we gain an understanding of how to capture a given scenario—environment, friendly, and enemy—in the model, and gain confidence that EINSTein works at this level of ground combat.

Once we are confident in our model, we can then use it to look at the future warfighting environments that the USMC might face and examine trade-offs between differing squad and fire team organizations. In a later section, we'll show a detailed roadmap for validating EINSTein that fills in the details of the left side of the figure.

As we mentioned above, the next two sections of this report provide an overview of our historical analysis and reasons for choosing EINSTein as our tool.

Historical analysis

While the historical record is full of changes in the Army's organization, the Marine Corps has remained relatively stable (a 13-man squad with three homogeneous fire teams). One might argue that if the Marine Corps' squad has remained fixed over the years, it has found the optimum organization. While that may be the case (we'll address differences between the Marine Corps and Army later in our analysis), the Army's experience definitely provides a wealth of examples that demonstrate changes in size or organization in response to various warfighting environments. Understanding the reasons for these changes—the driving factors—will help us examine the Marine Corps' squad in future warfighting environments.

This section is only a brief summary of our complete historical analysis (see [2]). Here, we've tried to capture the highlights.

Organization

First, we'll outline the methodology we used in our review. It is both historical (it looks back into the past) and extrapolative (it looks forward briefly into the future). One of the leading military historians of this century, Major General J.F.C. Fuller, once remarked, "Looking back is the surest way of looking forward."

This section is divided into several interrelated parts (this is also the organization of [2]):

- **Historical background:** We briefly explore how armies fought prior to the rise of squads. We look at the factors that led to the emergence of squads (a more detailed examination will follow in the next section). We will draw upon examples from various armies in order to draw out the key factors, or drivers, responsible for the emergence of the squad:

- — Technological and technical changes
- — Organizational and socio-cultural changes
- — Experiences wrought by combat particularly during the American Civil War, the Boer War, World War I and World War II.

- **The rise and development of the squad:** Having established the reasons behind the emergence of the squad, we address in detail the experiences of various armies as they struggled with the issues of right **size** and right **organization.** Our focus, is on the historical evolution of changes in the size and organization of squads in the United States Army (USA) and the United States Marine Corps (USMC). We found that the size and organization of USA squads have changed considerably more over the past 60 years than those of USMC squads. Has the UMSC found the optimal size and organization for the squad? If so, why has the USA not adopted the "tried and proven" 13-man squad of the USMC? We try to find some explanation for this in the section described below, with the caveat that this dichotomy between two services may need to be explored further.

- **Conclusions: past, present, and future:** Finally, we explore whether—and, if so, how and why—the complex warfighting environment of the 21st century will affect the size and organization of the squad in the USA and the USMC.

Development of the squad

The squad is a modern invention. In this context, it may seem odd to begin our discussion with the Roman Army. However, it is within that fighting force that we can see the genesis of a structure akin to the squad. The Roman Legion was divided into centuries of 80-100 men led by a centurion. Two centuries made up a maniple. Six centuries or three maniples made up a cohort. Ten cohorts formed a legion. What interests us is the smallest unit in the Roman Army, the *contubernium,* a party of **eight men** who shared a tent and a packhorse that transported their equipment and supplies. These men spent a lifetime together and built up a level of primary cohesion that was unique among armies of that era. The Roman contubernium is the direct ancestor of the modern squad.

Very little occurred between the decline of the Roman world and the rise of early modern European armies. In medieval times the individual knight reigned supreme as the key combat soldier until his overthrow by the longbowman.

From the mid-15th to the mid-19th century, after the invention of firearms, European armies developed the classic linear formation of musket-bearing infantrymen. Combat formations of the day were of a mass type, either in huge companies or battalions. Although the platoon existed and was the smallest fire unit, it rarely maneuvered away from its parent organization, the company, as an independent entity. The squad did not exist.

Technological changes

As long as the smoothbore musket reigned supreme, the opposing sides did not begin blazing away at each other until they were 50 yards apart. The invention of the rifle or rifled musket in 1849 *theoretically* changed all that. Fired from a rifle, the bullet would expand and be spun by the barrel's helical grooves. Such a bullet would travel further and was more accurate than the bullet fired out of the musket. Soon after that this revolution was solidified by the invention of the breech-loading rifle which allowed soldiers to take cover or "go to ground" to (re)load their rifles. This reduced vulnerability of the individual soldier but made command and control difficult. These two technological changes set the stage for the development of the squad.

Organizational and socio-cultural changes

Technological inventions or innovations often force dramatic organizational and socio-cultural changes in the human environment or social systems. The introduction of the rifle brought about organizational, doctrinal, and socio-cultural changes within militaries. Some of the changes were transitory; others proved to be wrong solutions. The rifle did not directly lead to the creation of the squad in the 19th century, as will become clear from the discussion below. However, it did set the stage for the emergence of this structure later on.

With the appearance of the rifle, theorists and practitioners of the art of war began pondering the following question: How could an assault unit of infantrymen "cross the deadly ground" and remain intact?[1]

The question that was posed with the introduction of the rifle in the mid-1800s, was still being asked well into the late 19th century: How does one deal with crossing the deadly ground? As one late 19th century military theorist put it:

> A certain space of from 1,500 to 2,000 yards swept by fire, the intensity of which increases as troops approach the position from which the fire is delivered, has to be passed over. **How shall it be crossed?**[2]

Within this larger question of how to cross the "deadly ground" lay three seemingly subordinate questions:

- Do you need to decentralize authority even further in order to be able to cross the "deadly ground?" (That is, can there be a combat element smaller than the company?)
- How small can an independent maneuver element be and still remain effective?
- How small can an independent maneuver element be and still include a useful mix of weapons?

On closer examination, the questions were to loom larger in the coming years, because the answers to them led to the emergence of the squad.

However, it was left to the Germans, who learned from the Boer War and their own experiences in the early stages of WWI, to set the stage for the emergence of the squad on the European theater of operations

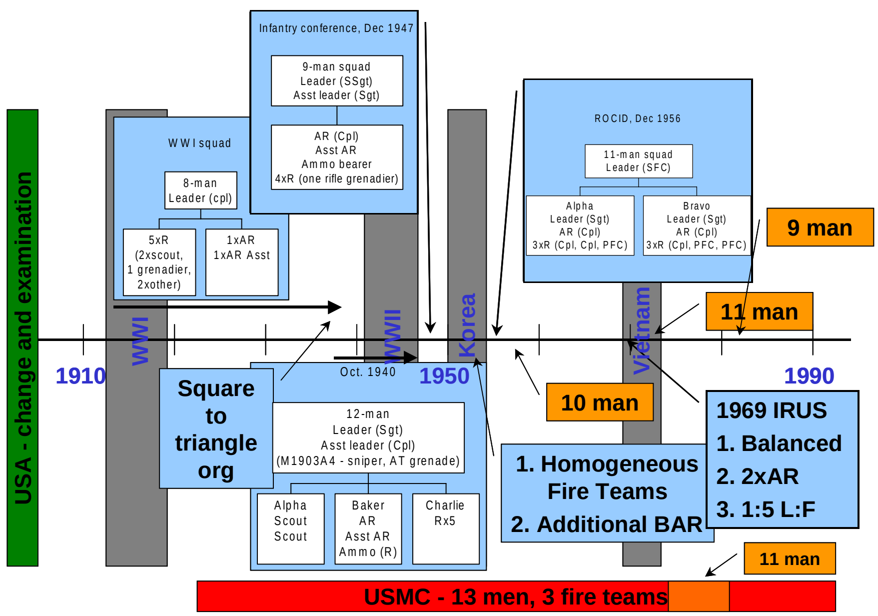
1. Note that we do not say an "infantryman" because individuals are bound to become casualties; what a unit needs to avoid is the destruction of unit cohesion as it moves into its objective.
2. Robert Home, *Precis of Modern Tactics,* London: Her Majesty's Stationary Office, 1882, pp.70-71.

a number of years after the technological revolution brought about by the rifle.

The rise and development of the squad

This section explores the rise and development of the squad from World War I to the present day. It also explores the determinants of squad size, organization and structure. We've only provided a small snippet of the historical development (see [2] for the complete discussion). Figure 2 shows an overview of how small unit (squad and fire team) sizes and organizations have changed since 1900.

Figure 2. Changes in squad size and organization since 1900



First, we should point out that most of the changes shown in the figure are changes to the U.S. Army's (USA's) squad. During most of this time, the Marine Corps' squad only changed in size once (from

13 men to 11), and its organization remained three homogeneous fire teams.[3]

In grey, we show four of the wars that have had the most impact on the Army squad; in blue, the changes in the organization of that squad; and in orange, the changes in squad size. As you can see, the Army squad has ranged in size from 12 to eight men, and in organization from three heterogeneous fire teams to no fire teams.

Impact of technology

Entering WWI, changes in military technology had a dramatic impact on *how* squads evolved, while the deadlock on the trenches played a key role in *why* squads evolved.

In 1914, the Imperial German Army, like other European armies, expected a short war based on infantry actions. By that time the machine gun had replaced the rifle as the predominant weapon of infantry units. But the machine gun of the time was very heavy and thus not very mobile. This made it beneficial to the defender, not the attacker. The rifle could not overcome the heavy machine-gun (HMB) in a contest of firepower. By late 1917 the situation had changed dramatically, enabling the Imperial German Army to undertake some brilliant breakthroughs in March 1918. What had happened? The German success stemmed from the development of the light machine gun (LMG). This enabled the Germans to change their infantry organization and size to take advantage of the mobility of the light machine-gun. In this context, the Germans developed small-units called *Stosstrupps* or *Sturmtrupps* (assault squads). Each of these new squads consisted of eight men and a non-commissioned officer. The essence of the new German assault tactics was that attacking infantry should be able to react rapidly and effectively to the resistance of the defending enemy. The key to this was the

3. By homogeneous fire teams we mean fire teams with the same composition—for example, two riflemen, one machine gunner, and one grenadier. A 13 man USMC infantry squad has three of these fire teams and a squad leader.

decentralization of command so that squads could operate on their own initiative according to the evolving combat situation.

Impact of combat experience

The United States Army entered WWI with the small-unit structure developed by Emory Upton. However, at that time it was essentially an administrative rather than a combat element. Under the influence of the French Army was considered to be at the cutting edge of the development of small unit tactics—this informal American squad quickly evolved into something bigger, the **16-man section.** Two squads made up a section or "half platoon."

On the eve of U.S. entry into World War II, General Leslie McNair ordered an extensive and exhaustive reorganization of the squad. The conclusion of the committee that presided over this reorganization was that the eight-man squad with which the army went to war in 1917 had not been large enough to absorb casualties and continue to function as an effective and cohesive unit. The committee's recommendation was that the army should adopt a **12-man squad.** The automatic rifle team was eliminated and the Browning Automatic Rifle (BAR) was incorporated directly into the squad as an integrated three-man team (two of them armed with the M-1 rifle and one with the BAR). A sniper was added to the BAR team, making it, in effect, a four-man team. With a sergeant as the leader of 11 men, the squad had grown to be almost comparable in strength and combat capabilities to the rifle platoon of WWI.

USA in WWII

During WWII, the 12-man squad was broken down in the following manner: a two-man scout team (ABLE), a four-man BAR team (BAKER), and a five-man maneuver and assault team (CHARLIE). According to the "theory," the squad leader would stay with ABLE until the enemy was located and fixed (pinned down by fire). Once this was accomplished, the squad leader had to rapidly formulate an assault plan. In this context, he would signal BAKER to provide covering fire, while he then made his way to CHARLIE to lead the assault by short rushes. That was the theory. The reality proved markedly different:

- The squad leader often found himself pinned down with ABLE once contact was made with the enemy. He could not make his way back to CHARLIE to lead it into the assault.
- The squad leader found the 12-man squad difficult to control.
- Two or three casualties within the ranks of the CHARLIE assault team degraded the integrity and cohesion of this team, thus making the assault very difficult to undertake.

USMC in WWII

The United States Marine Corps adopted a different philosophy from that of the United States Army. The experiences of the Marine Corps in "small wars" in such places as Nicaragua and Shanghai in the early part of the 20th century had taught the USMC the importance of the automatic rifle as a base of fire. Furthermore, during WWII the USMC found itself fighting in an environment, jungle and island warfare, that was different from the Army experience. Last but not least, amphibious operations became the hallmark of the USMC.

By the beginning of WWII, the Marine infantry platoon comprised a seven-man headquarters, an eight-man BAR squad, and three **nine-man** rifle squads. Each squad consisted of a squad leader, a BAR man, six riflemen, and a rifle grenadier armed with a grenade launcher.

With the onset of WWII the platoon and squad organization described above was found to be sub-optimal particularly for both jungle and island fighting. Consequently, the officers of the USMC introduced the most dramatic revolution in the USMC infantry squad. First, the BAR squad disappeared from the platoon. Second, the rifle squad was increased in size to **12 men.** This squad comprised a squad leader, an assistant squad leader, six M-1 riflemen, two assistant BAR-men armed with M-1s, and two BAR-men. This organization structure allowed the rifle squad to be broken down into two six-man fire units, each containing an automatic rifle and five semi-automatic rifles.[4]

4. Some Marine units, particularly elite raider or commando units experimented with different structures. For example, the Second Raider Battalion retained nine-men divided into three fire groups of three men each. This is the organization that remains today.

Korea

The combat experiences of Major General Fry were also to affect U.S. infantry tactics. Fry was the commander of the Second Infantry Division in the Korean War, during which time he instituted modifications in infantry tactics. Fry ordered his division's infantry squads to deploy into two "battle-drill" (i.e. fire and maneuver) teams. One team would act as a base of fire while the other would maneuver. After the war, Fry rationalized his modifications in his two-part article, "Battle Drill," which appeared in an edition of the unofficial but well respected *Combat Forces Journal.* In his article, Fry claimed that his introduction of fire and maneuver teams eliminated "pin-downers," soldiers who could not move because they were pinned down by enemy fire.

Marshall's observations on firepower (he recommended a BAR in each fire team) and Fry's modifications ensured that the debate on squad *organization* and *size* would continue unabated in the aftermath of the Korean War.

Important factors and conclusions

Based on our historical analysis, we conclude that the following criteria stand out as the key drivers of squad size and organization:

- Firepower: This can be seen as the "measure of suppression potential (of the squad) based on the numbers and types of weapon systems carried by the squad." Firepower is integral to the overall success of the squad mission, its ability to engage in fire and maneuver, and its ability to ultimately dominate the enemy in the close fight. However, many of the studies and experiments added a word of caution with their admonition that there comes a point beyond which adding more weaponry does not lead to a commensurate increase in firepower. Furthermore, firepower tends to slow down the squad. There is an old saying in the infantry, that the squad can only move as fast as its slowest member(s): the machine-gunner and his assistant. In this context, as we look to the future and the development of exotic and advanced infantry combat weapons, it's clear that firepower will continue to be a strong driver of squad success.

- Resiliency: This is the ability of the squad to sustain combat losses without losing its identity, cohesion, and, above all, its ability to continue with the mission. Naturally, the larger the squad, the greater the resiliency. Will resiliency be important for the future? All evidence points to the continued importance of resiliency in the combat of the future where the asymmetric, non-linear warfare environment will play a determining role.

- Maneuverability: The other term for this is “control.” More accurately, its the ability of the squad leader to control the movements of his squad under fluid and dynamic combat conditions. It is affected by the size of the squad—the larger the squad, the more difficult it is to maneuver—and by the ability of the squad leader to communicate with his squad members. All indications are that maneuverability will continue to be an important factor in the future.

- Mobility: This is not the same as maneuverability! It is the measure of the squad’s ability to move towards an objective and the physical ability to conduct movement, particularly under fire. While maneuverability depends more on the squad leader’s abilities and on communications, mobility is dependent upon the entire squad in the sense that it requires their physical and psychological conditioning to be at a high level.

These factors, that throughout history have been the determinates of squad and fire team success, hence the drivers of changes in squad size and organization, together with the associated historical vignettes (the highlights presented here and the wealth of data in [2]) provided us with the ammunition we needed to test our model.

Modeling

This section provides a brief overview of the modeling world, and discusses in detail the entity model—EINSTein—we chose as our tool to analyze ground combat. Toward the end, we'll focus on how we used EINSTein to model small unit engagements.

Choosing the model

When it comes to the actual modeling of ground combat there are generally two approaches, mathematical models and simulation models. In this case, the term simulation means computer simulation and not a physical simulation or war game that might take place at a military warfighting lab. When investigating the analytical modeling of combat, we must make the assumption that the nature of combat is quantitative, and thus quantifiable [3]. The best definition of "ground combat" that seems to match the historical record is that of Ancker ([3], p. 178), which states, "Combat is the end result of a hierarchy of smaller firefights."

The standard bottom up representation of combat is that of firefight–engagement–battle–campaign–war. In our analyses, the bottom end needs to be lowered a few levels to properly account for engagements at the squad and fire team level. So in the ground combat study, we are dealing with a much different situation than is usually encountered in combat modeling. That is, we are dealing with small, mobile units (i.e., fire teams) with specialized weapons, and **not** large aggregations of troops. The uncertainty present when dealing with small mobile units makes the process of analytical modeling more difficult by orders of magnitude. Indeed, theory, reason, history, and field experience have all shown that the firefight is a "comparatively small, terminating stochastic attrition process" ([3], p. 175). And since probabilistic elements ranging from human choice to weapons hit and kill probabilities are all important in ground combat, that process is itself necessarily probabilistic and uncertain in nature (i.e., it is not deterministic).

In general, there are two classes of combat models: deterministic and stochastic. Table 1 list the typical combat models we'll discuss below.

Table 1. Typical combat models

Model	Problem
Deterministic models	
Deterministic Lanchester	- Ignores stochasticity
Other Deterministic	- May have no rational basis - Highly aggregated models based on historical curve fits - Modeled to obtain desired result - Ignores stochasticity
Stochastic models	
General Stochastic	- Difficult to obtain solution due to large computational times
Renewal Stochastic	- Based on faulty reasoning and difficult to solve
Exponential Stochastic	- Deviated from combat reality to far to be of utility
Markov Stochastic	- Next event depends only on current event - Very limited research as been performed on this technique to test its validity

Deterministic models

The simplest and most widely used deterministic model is that developed by Lanchester. The equations which govern this model are the so-called Lanchester equations, which are in their most general form:

$$\frac{d\mathbf{X}}{dt} = -A\mathbf{Y} \tag{1}$$

$$\frac{d\mathbf{Y}}{dt} = -B\mathbf{X} \tag{2}$$

with initial conditions:

$$X(0) = X_0 > 0 \tag{3}$$

$$Y(0) = Y_0 > 0 \tag{4}$$

Here **X** and **Y** are the vectors representing resources, including troops, tanks, missiles, etc., of the two opposing forces. The matrices **A** and **B** are the attrition matrices, whose elements are the number of corresponding resources removed by a single corresponding resource per unit time. These equations represent mutual attrition between two largely aggregated forces are under continuous combat with similar weapons and resources.

The solution to the above set of coupled ordinary differential equations is the so-called *state equation solution*, also known as Lanchester square law:

$$B^2 = B_0^2 - \frac{\alpha_R}{\alpha_B} \times (R_0^2 - R^2) \tag{5}$$

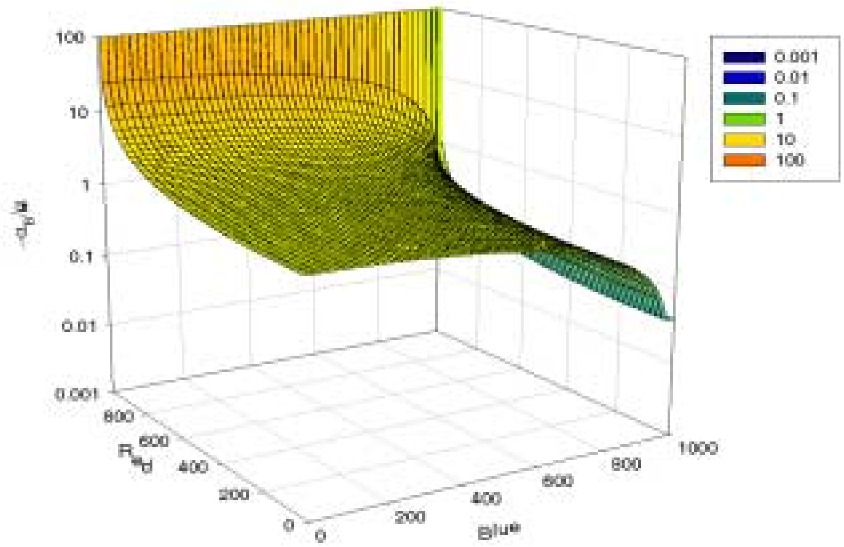
Scales ([3], p. 345) indicates that this solution is found to match the two extremes of both a target-rich environment and a target-acquisition-driven environment, the former simply meaning “few shooting at many” and the latter meaning “many shooting at few.” But, as we shall see, this simple solution has many drawbacks. This equation is plotted in figure 3.

Examining the figure, we see the behavior we should expect from the sine-squared solution. For a given number of Blue agents (choose 400), when we increase the number of Red agents from 0 to 1,000, the the ratio of the attrition coefficients increases over 1000 times.

Although the Lanchester equations are conceptually straightforward they rarely, if ever, are useful in the accurate modeling of large scale combat unless detailed time-dependent attrition coefficients are known a priori. And, when dealing with small-scale stochastic combat with non-aggregated entities, i.e., individual agents, and weapons, they are even less useful—and **strictly not** applicable.

Not really discussed here are the other types of deterministic models which are largely “curve fitting drills” that also rely on attrition coefficients. For most of the reasons listed above, these models are also not appropriate for our work.

Figure 3. Ratio of attrition coefficients as obtained from the sine-squared solution of the Lanchester equations



Stochastic models

The class of combat models which introduce probabilistic elements into the system are called *stochastic* models. These models tend to lend themselves to the analysis of small-scale firefights. The most common of these, which are termed *general renewal* (or just *general* or *renewal*), are essentially exponential Lanchester models which allow the firing time of the agents be a random variable. These models are often just referred to as GR models.

The crux of the model lies in the definition of the state probability, or state function, **P**. The state function $P_{a,b}(t)$ is defined as the probability that the combat is in state (a,b) at time t. These state probabilities contain all the information about the system and thus all the necessary combat variables may be derived from them. They are exactly analogous to the state functions commonly seen in quantum physics. The time evolution of the combat state function is usually cast in what is known as the Kolmogorov equations, written here in vector form as ([3], 374):

$$\frac{d}{dt}\mathbf{P}(t) = \mathbf{g}(\mathbf{P}, \mathbf{r}) = \mathbf{f}(\mathbf{P}, \alpha) \tag{6}$$

where $\mathbf{P}(t)$ is the time-dependent state function vector, $\mathbf{r}$ is the vector of probabilistic kill rates for each state, and α are the conditional kill probabilities for each state. The initial conditions on the state function are $P_{a_0, b_0}(0) = 1$, $P_{a,b}(0) = 0$ for all other states. Also, since we are dealing with a probability, the sum over all states must be equal to one, that is:

$$\sum_{a,\, b \in R} P_{a,b}(t) = 1 \tag{7}$$

Although the GR formulation can be cast in rather straightforward form of equation 6, the solution of the equations is quite difficult and is generally restricted to very small engagements with the same number of combatants on each side (i.e., three on three, or four on four).

The *m* on *n* engagement is even more difficult. Extremely large computation times are necessary because the relative error in the solution is inversely proportional to the square root of the sample size for the *m* on *n* models. This makes it extremely difficult to examine the effect of squad and fire team organization on ground combat.

Approximations to the GR stochastic equations do exist but generally give poor results. The approximate solutions, such as the homogeneous solutions, all have simplifications which make them essentially no better than Lanchester models. Common assumptions to the homogeneous solutions include homogeneous force and weapons assignments, continuous (although stochastic) time engagements, and firing targets which are chosen completely at random. In addition, no decision structure may be included, they have no ability to vary sensor and fire ranges, and they have no ability to take into account many of the intangibles such as communication, personality, and leadership. It's important to note here that these reasons alone, the inability of these models to recreate the true nature of combat and their inability to capture the parameters we would like to include in our model make them inappropriate for our work.

Table 2 shows the growth of computational time and estimated CPU time for the exact solution and the Homogeneous Combat Approximations to stochastic combat (HCA1 and HCA2) proposed by Yang and Gafarian ([3], p. 357). As you can see, the computational time grows exponentially. The approximate solutions have much smaller CPU times but are still unacceptable because of the simplification required to get a solution.

Table 2. Growth of computational time and estimated CPU time for the exact stochastic GR model and two approximate homogeneous solutions[a]

Algorithm complexity	Analytical solution	HCA1 solution $O(N^2n+Nn^4)$	HCA2 Solution $O(Nn^4)$	CPU time (analytical)	CPU time (HCA)
n = 1	1	1	1	2 (h)	0.082
n = 2	150	2.1	16	300 (h)	1.312
n = 3	5.1 (h)	3.4	81	4.3 (h)	1.05
n = 4	28 (d)	5.3	256	560 (h)	1.38
n = 5	10.8 (y)	8.1	625	10^4 (y)	1.855
n = 10	10^{12} (y)	60	2.8 (h)	10^{16} (y)	19.52
n = 20	10^{45} (y)	816	44 (h)	10^{49} (y)	73.64

a. Here, N is the total number of grid points, i.e., (a,b) states. The total number of agents is represented by n. Units are in seconds unless otherwise noted. CPU time is estimated using speed of Solbourne Series5e/900 System. The first three columns represent ratio of time, using n=1 time as a baseline ([3], pp. 376-377).

The computational complexity is obvious. For a scenario with just 5 agents per side (n=5), an estimated CPU time of 10^4 years is required to obtain a solution. And while the homogeneous combat approximate solution are much faster, with only 1.855 seconds of CPU time, they do not consider the factors we need in our analysis.

Finally, all the above listed models, including the different variations of deterministic and stochastic models, have a few common problems the make them unacceptable for our use in the ground combat study:

- The deterministic models cannot capture stochasticity—probabilistic elements cannot be included in the analysis.
- Stochastic models cannot model large-scale systems or multiple-interaction small-scale systems, due to solution complexity and calculational error.
- The true sporadic nature of combat does not emerge in either class of models.
- Both deterministic models and homogeneous stochastic simplifications of the GR models assume homogeneous forces, continuous combat, and battlefield "omnipotence."

And herein lies the problem: If the true sporadic nature of combat cannot be properly represented, then we cannot properly explore the complex relationships between the variables of combat and their relationship to the outcome. How do we look at terrain? At weapons systems? At different squad organization?

Recently, developments in the area of complexity theory have given us a new technique—*agent based modeling* (ABM).

A new approach—agent-based modeling

Fortuitously, an interesting new modeling development is taking place at CNA. EINSTein, an agent-based model, seems to capture many of the complex set of behaviors and variables we require for our analysis of ground combat.

Recent research using EINSTein performed in New Zealand [4] indicates that EINSTein correctly models the non-linearity of the pay-off of higher kill probability. That is, the relationship is that of a power law instead of a direct proportional relationship. In fact, an important finding is that EINSTein predicts that the attrition rate is proportional to the cube root of the kill probability. Furthermore, the complex adaptive model of EINSTein may indeed give rise to turbulent dynamics that are often seen in ground combat, including discontinuous behavior in the attrition function and other attrition-related behavior such as casualty clustering.

The agents present in EINSTein have the capability of exhibiting the characteristics of doctrine, mission, situational awareness, adaptability, personality, aggressiveness, etc. These values encompass many of the previously mentioned intangible variables. And, since they can be modeled, they can be controlled. This is important as these intangible variables are not the important driving factors we'd like to explore. At the same time, EINSTein also treats the important tangible factors including terrain, weapons, command and control, and many others. Thus, we choose to use EINSTein as our candidate tool for examining ground combat.

Using EINSTein

Here, we'll quickly review how we used EINSTein in our ground combat analyses (for a more complete description of the model and how to use it, see [1] and [5]).

EINSTein is an improved version of its predecessor, ISAAC,[1] that has been enhanced to allow the user to simulate a wide range of squad and fire team behavior. With EINSTein, we can explore squad sizes and organizations, terrain effects, weapons trade-offs, communications and sensor capabilities, and many other ground combat variables. In addition, EINSTein allows multiple runs, extensive data collection, and internal calculation of various statistical MOEs such as force attrition, position, and dispersion.

While EINSTein has a number of strengths that make it ideal for our work, there are also some challenges. First and foremost, EINSTein is still in the developmental phase and the results of the model have not yet been demonstrated to be credible at the squad and fire team level (the next section outlines our scheme to answer this credibility challenge). While others are applying EINSTein to broader operational and theoretical problems (see references [4] and [7]), we are focused on small ground combat engagements. Thus, while EINSTein appears to model squad combat, we will first need to ensure that we are comfortable with the results and that the model does a

1. For a description of ISAAC, see reference [6].

good enough job of representing reality at the small-unit level. The second challenge is that, as with any multiparameter model, we'll need to ensure that we vary only selected parameters and don't end up "fitting the data" with a multiparameter equation. One big advantage of our model over field tests is that EINSTein does allow us to define and control the "intangible" variables we discussed earlier; thus, we don't have to correct for things such as training and morale. With EINSTein, as you'll see below, we define a "brave" squad of Marines for use throughout our work.

EINSTein's parameters

EINSTein has the capability to vary a wide range of individual and group parameters. In this section, we'll briefly discuss how we used the model and how we chose the parameters for each of our runs (see [1] for more information).

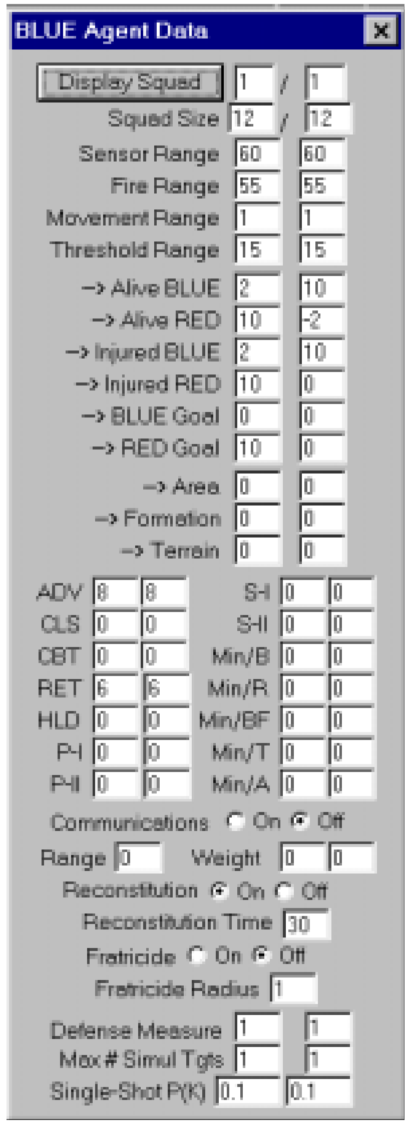
We'll discuss first the individual parameters, then the parameters in EINSTein that influence group behavior, and finally the weapons parameters and how we scaled them to a realistic battlefield.

Individual parameters

EINSTein is at its core an entity model. As one might expect, there are a multitude of parameters that influence the behavior of the entities in the model (they are grouped into a Blue and a Red force). Figure 4 shows a screen shot of the Blue force parameters in EINSTein. Reading from the top of the figure, the first two variables are the squad number and size (here, one squad of 12 entities is defined). This is where the user can define fire teams and squad organizations. For example, later in this section we'll discuss results from a 12-man squad, with two 6-man fire teams. The next four parameters are various ranges including the sensor range (set to 60 in our example) and the weapons range (set to 55 in our example). The ranges can have different values for alive and injured agents[2] (the two columns)—here they're the same.

2. Currently in EINSTein an agent is either alive, injured, or dead (three states).

Figure 4. EINSTein's agent parameters



Next, come a series of individual agent parameters again in two columns. Each indicates the weight that a Blue agent moves toward (or, with a negative value, away from) other agents, or goals. In the example shown, an alive blue agent has a five-times-greater weight of moving towards an alive enemy or the enemy's goal. When injured, a Blue agent would rather move away from the enemy and cluster with his comrades.

Before moving on to the group parameters, we should note here that we chose the Red and Blue entity parameters for both the forces (both squads are the same values) to represent a relatively aggressive (but not suicidal) squad. Throughout the results shown here, and throughout these analyses, we have not varied the entity parameters. Remember, it is these parameters that capture many of the intangible factors (such as bravery, cowardice, and loyalty), and we wanted to control these parameters throughout our work.

Group parameters

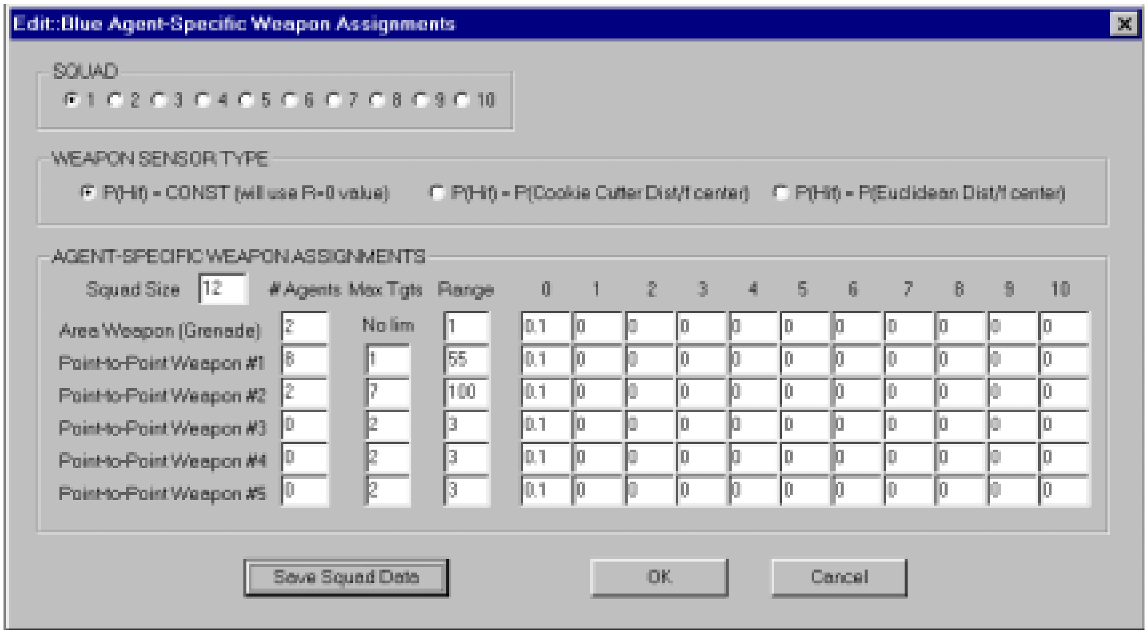
Next comes a large set of parameters (again for the two entity states) that influence group behavior. We won't discuss many of these here, but want to point out that the advance parameter and the retreat parameters (set to 8 and 6, respectively) set thresholds for squad behavior. We set the values in these parameters to ensure that the squads will fall back if a certain level of attrition is reached—here, six men. Throughout our work, we used none of the other group parameters. Finally, at the bottom of the figure are a couple of weapons parameters, discussed below.

Weapons parameters

As we mentioned above, the entity parameters (figure 4) included two of the important weapons parameters. When the entire squad has the same point-to-point weapon (a rifle or machine gun), the user can enter these parameters here. The single-shot Pk is the probability of hitting an entity that is targeted, and the number of simultaneous targets indicates how many individuals can be engaged simultaneously with the rifle. In our example, one entity can be targeted (EINSTein will choose one at random from all those in sensor range) and will be hit with probability .1.

Figure 5 shows an enhanced set of weapons parameters. These parameters were added to the model early in our work to give us the ability to vary the squad weapons set and give each squad a realistic assortment of weapons. Using these parameters, we can assign and define weapons such as grenades, rifles, and machine guns.

Figure 5. EINSTein's weapons parameters



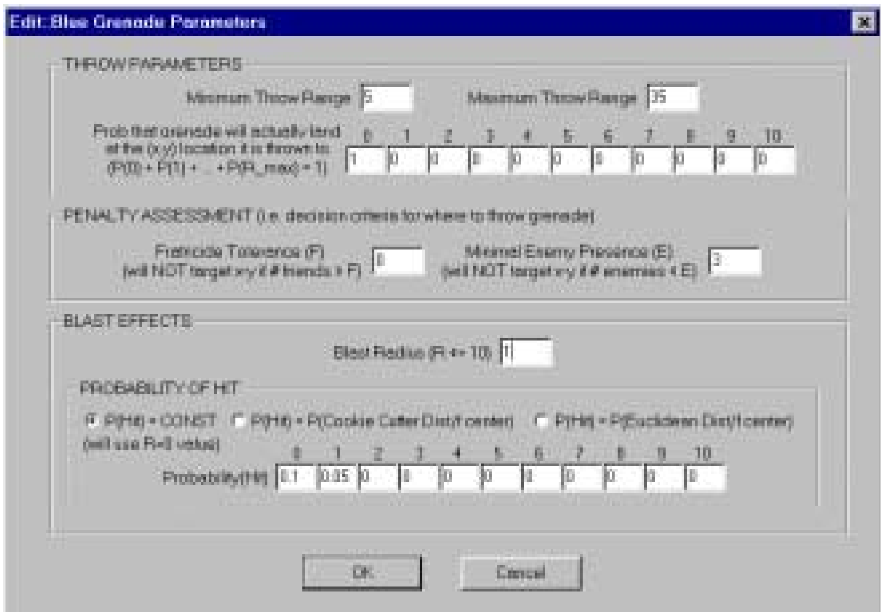
Moving from left to right, the radio buttons at the top allow the user to choose the squad we're assigning weapons and the type of Pk distribution (at this point in our analysis, we've only used a constant Pk). At the bottom, various weapons can be assigned to members of the squad. In the figure, 2 of the 12 members of the squad get grenade launchers (the range shown is the burst radius); 2 have machine guns (those at the bottom with a range of 100 and seven simultaneous targets, and the remaining 8 have a single-shot rifle (with a range of 55).[3] As we'll discuss below, these parameters are based on real squad weapons.

Finally, figure 6 shows the grenade parameter screen. Here the user can define the grenade parameters—ranges, accuracies, thresholds.

3. As we'll discuss later, we chose these parameters to represent real squad weapons. In EINSTein a machine gun can be represented by a higher Pk, or as we did here with more simultaneous targets—an entity with this machine gun can shoot 7 other agents each move with Pk .1 at a range of 100.

The grenades have a range of 35, a probability of 1 of hitting where they're aimed (the second row of probabilities set the accuracy of the launcher—here, 1 at the point of impact), will be targeted against groups of three or more of the enemy, have a blast radius of 1, and a Pk of .1 at the point of impact, and .05 at the blast radius.

Figure 6. EINSTein's grenade parameters



With the three screens above, and the addition of two others that define terrain and its effects on the entities, we have the flexibility to capture all of the squad behaviors we planned to analyze in our work.[4]

Scaling the weapons

EINSTein has maximum and minimum limits for most of the spatially dependent variables. For example, the maximum battlefield size is

4. EINSTein includes the capabilities to vary a wide range of other parameters, including squad and fire team leader characteristics and communications parameters. We have not yet used any of these in our analysis.

150 units and the minimum box size is 1 unit, which gives a maximum of 150^2 total units to cover the battlespace. All other ranges, such as movement range, sensor range, communication ranges, and point-to-point and area weapon ranges must all fall within these limits.

If we take a point-to-point weapons range of 1,000 meters for the machine gun, 550 meters for the rifle, 350 meters for a launched grenade with a burst radius of approximately 10 meters,[5] and a maximum battlefield of 150, we obtain some fundamental scaling ratios:

$$\underline{\text{machine gun}}\text{:}\ \frac{150}{1000} = 0.15 \tag{8}$$

$$\underline{\text{rifle}}\text{:}\ \frac{150}{550} = 0.27 \tag{9}$$

$$\underline{\text{grenade}}\text{:}\ \frac{150}{350} = 0.43 \tag{10}$$

To scale our weapons parameters to the maximum battlefield size, we take the smallest number (0.15) for our scaling parameter and divide the ranges. This leaves us with a set of battlefield-scaled weapons parameters {R} such that:

$$\{R\} = \left\{\begin{array}{c} R_{MG} \\ R_{rifle} \\ R_{grenade} \\ R_{burst} \end{array}\right\} \approx \left\{\begin{array}{c} 150 \\ 83 \\ 53 \\ 1.5 \end{array}\right\} \tag{11}$$

The smallest unit on the battlefield is one space, and we'd like some time at the start of the run where the entities are out of range, so we scale everything to one unit by dividing by 1.5. This gives us the scaled ranges shown below:

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5. We've based our weapons on the typical squad weapons—the SAW, M16, and M203 launched grenade.

$$\{R\} = \begin{Bmatrix} R_{MG} \\ R_{rifle} \\ R_{grenade} \\ R_{burst} \end{Bmatrix} \approx \begin{Bmatrix} 100 \\ 55 \\ 35 \\ 1 \end{Bmatrix} \quad (12)$$

These ranges allow us to choose a battlefield size of 100 by 100 in all the runs except those with machine guns. There, when a squad has a machine gun, we use the maximum battlefield of 150 by 150.

An additional problem arises once the battlefield and weapons ranges are scaled to "real-world" conditions. Here we have defined a single unit on the battlefield by the blast radius of a launched grenade at 10 meters. The problem deals with the scaling of the other ranges such as movement, sensor, and communication ranges. EINSTein originally handles these ranges on the assumption of a ladder-like organization of scale sizes, shown below.[6]

$$\begin{Bmatrix} \textit{movement range} \\ \textit{sensor range} \\ \textit{communication range} \\ \textit{fire range (F)} \\ \textit{battlefield size (B)} \end{Bmatrix} \sim \begin{Bmatrix} 1 \\ 10 \\ (10^1 \rightarrow 10^2)F \\ 10^2 \rightarrow 10^3 \\ B \gg 1 \end{Bmatrix} \quad (13)$$

Thus, for our scaled battlespace there is a large discrepancy between the weapons range, the movement range, and to a lesser degree the sensor range. Without modification, EINSTein would have had the agents moving one to three orders of magnitude faster than they could in real life. With our scaled battlefield, each movement is 10 meters and it occurs as quickly as an entity can shoot. If we assume that a rifle can be fired every couple of seconds, then the entity that

6. These ranges come from a discussion with the creator of EINSTein, Andrew Ilachinski.

moves every time the rifle is fired is advancing at roughly 10 meters every 2 seconds (about 10 miles per hour).

To solve this problem, and slow down the entities, EINSTein was modified to include a time delay so that the agents only move after a certain number of time steps, *N*. This seems to slow the agents down so their speed matches real rates of advance and scales with the other battlespace parameters.

For our work with EINSTein, we used the scaled weapons parameters shown above and a movement factor between 2 to 5. But, we found early on that the delay factor had no effect since we've used Pks that are simple step functions. When an agent is in range, he's got the same probability of being killed at any range less than the maximum. So whether he's advancing or stationary he has the same probability of being hit.

Running EINSTein

In most of our work, we've used EINSTein's multiple-run mode. EINSTein has extensive data collection capabilities. We've relied on the model to gather the relevant statistics, and, as you'll see, prepare much of the data.[7] Typically, we've found that doing 40 runs of 150 time steps takes only a matter of seconds, and allows the data to converge nicely.

Next, we'll turn to our plan to ensure that EINSTein was working in the small unit regime.

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7. An additional change that we needed early on was the ability to count shots and hits. Firepower and accuracy measures are often important statistics in comparing ground combat engagements.

Road ahead

While we agreed that there were some challenges to using EINSTein as our tool, ultimately we believed, as we discussed earlier, that the model was our best hope for an analytical solution to the issues we're exploring in this project.

First, however, we needed to ensure that EINSTein was a useful tool for small unit engagements. As an aside, when we say "believable" we mean believable to other analysts (perhaps the lower of two bars), and believable to a typical Marine familiar with ground combat (the higher of the two bars)—our intended future audience. A typical Marine will look for things in the model that are intuitively obvious; if he/she doesn't see these things (or have his/her intuition changed), it's doubtful that the remaining results will be embraced.

You'll remember that in our methodology, we planned to use historical data to ensure that whatever tool we chose was giving believable results. To that end, we proposed the following set of steps to ensure that the model agrees with some simple precepts in ground combat and recreated what history has shown to be important.

- Use historical data.
  - Choose a set of relevant historical examples (where we understand the cause and effect of changes in squad size and organization).
  - Recreate the situation (environment, enemy, friendly forces, etc.) in EINSTein.
  - Look for similar results (for example, in Korea, squads with fire teams performed better than those without).

- Walk before running.
  - — Outline a set of steps (a roadmap) with feedback at each step.
    - – Start with some examples of known behavior in simple situations—i.e., validate our intuition.
    - – Gain confidence with our understanding of the model, and with its ability to recreate the changes in squad sizes and organizations as a result of changing factors (such as weapons technology).
  - — Build in complexity (more complex examples and concepts) as we succeed, or ensure that we understand why our model doesn't give a reasonable answer.
- Finally, when we are confident about EINSTein's ability to simulate squad interactions on the battlefield, we'll add in the history and USMC examples.
  - — Add in USA experience over the years.
  - — Add in recent USMC exercises Hunter/Urban Warrior.

Showing that the model does, in fact, find the same types of answers as were seen historically—the same trends in squad size/organization seen in a series of tests/combat—will allow us to move forward into our analysis of the Marine Corps future, confident in our tool. It's important to note that this "agreement" with history will allow us and the Marine Corps to become confident with EINSTein as an analytical tool.

As you've seen, our historical examples include a set of factors (such as firepower, and mobility) and changes (such as adding a third fire team) that have been proven historically. While some of these decisions were later reversed as the driving factors, or their relative weights changed, they were valid at the time and provide a clear link between the factors and the change in size or organization of the squad. Our plan is not to focus on the individual battle—which could easily have been influenced by one of the intangible variables, such as bravery—but rather to look with a wider lens at institutionalized changes in squad size and organization that were shown to be necessary over a series of battles (such as the addition of fire teams to the USA infantry squad at the end of the Korean war) in response to tangible factors.

Before sitting down and attempting to use the model to simulate a complicated set of tests or combat environment, we first needed to become comfortable with the basics of EINSTein and the results we're seeing. To that end, we sketched out a set of basic combat examples, increasing in complexity, that have a well-known "answer." Walking through these examples allowed us to become comfortable with how simple parameters such as weapons usage, terrain, and squad organizations are captured in EINSTein.

Figure 7 outlines the first five steps in our roadmap for using EINSTein to examine ground combat at the small unit level—at this point, most have been completed (see the results section of this paper). We've outlined a series of increasingly complex examples where we can predict what we expect to see in the model. Our goal was to gradually gain experience using EINSTein and confidence that it recreated those basic aspects of squad-level combat.

Figure 7. Road ahead (first two phases)

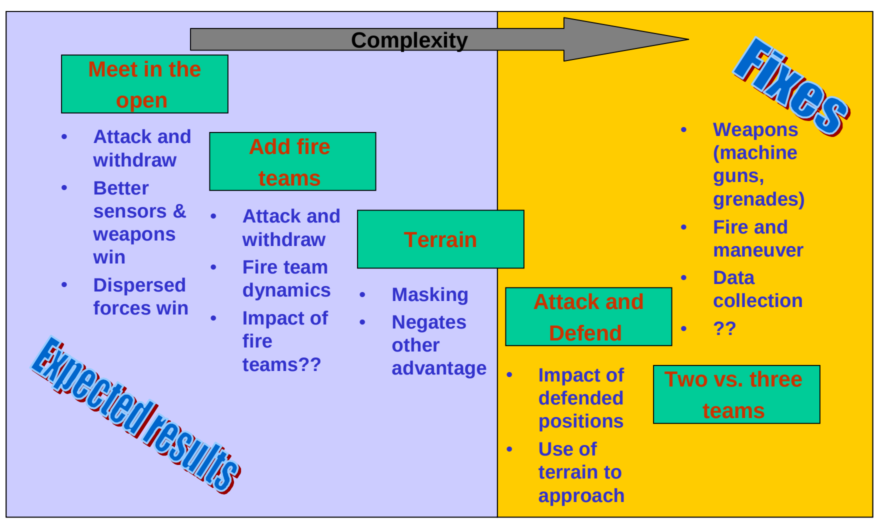


Figure 7 shows the steps (in green) in our validation process, the expected results (underneath), and the EINSTein fixes that might be required (to the right). As we'll discuss later, particularly with the scaling of the weapons, our projected list of fixes was by no means exhaustive.

The first step was to model encounters between squads in the open—the most basic ground combat engagements. In a set of runs, we planned to vary sensor and weapons characteristics (for example, give one squad grenades) and look for intuitive answers. For example, we expected that the squad with better weapons would inflict more casualties, and that the weaker squad would attempt to withdraw as its casualties mounted. The ability of EINSTein to capture typical squad responses (for example, withdrawing as casualties mounted), was important—its something a typical Marine would expect.

Second, we planned to add fire team dynamics to our encounters. Here, we expected to see differences in the way a squad with fire teams acts as compared to a squad without fire teams. Historically it's unclear that in the open (without terrain effects), fire teams really matter much; numbers and firepower are the key. Therefore, we thought that we might not see any attrition difference. As we moved into combining squad organizations with terrain, we expected to see differences in success.

Third, we wanted to look at the effects of terrain—an important factor in squad engagements. Here, we would expect to see things such the masking effects of terrain and forces using terrain to negate other advantages such as weapons or sensor ranges.

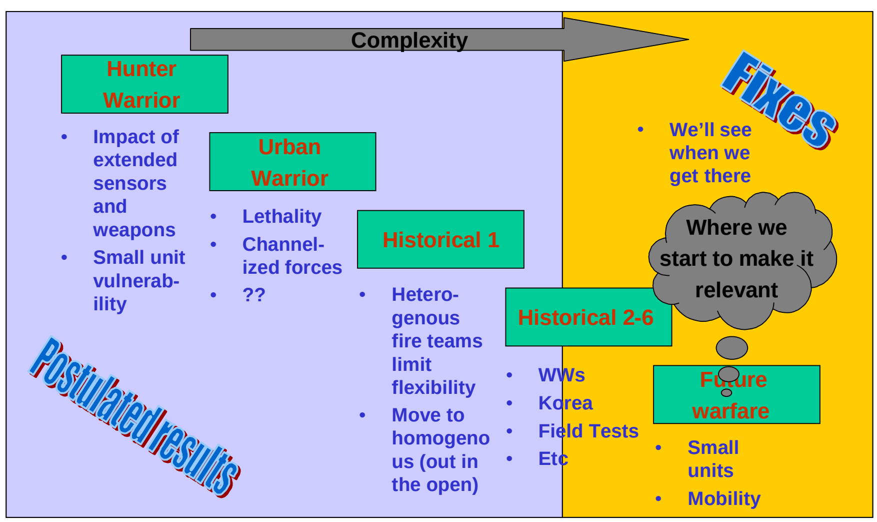
Fourth, we planned to examine some classic attack-and-defend scenarios. Here, we wanted to look for the typical success ratios in the attack. We also planned to look at the impact of terrain in allowing an attacker to approach a position undetected.

Finally, we really wanted to look for the difference between two squad organizations (USA vs. USMC). The major difference in this example is the trade-off between size of fire teams and their number.

Assuming that we were able to successfully complete the steps outlined in figure 7, we planned to increase the complexity in a series of historically relevant examples and vignettes that capture the recent experience of the Marine Corps in MCWL experiments, figure 8. We hoped that by this time, our proficiency with the model would have increased, along with our instinctive feeling that EINSTein was capturing the necessary detail of ground combat engagements and giving the right answer in terms of our historical analysis and our intuition. As we'll see in our results section, many of the runs in phases three and four remain to be carried out.

We'd like to first examine the recent USMC exercises (Hunter and Urban Warrior) and see whether we can reproduce some of their important findings. For example, in Hunter Warrior we'd like to examine the impact of increased sensor and weapon ranges on small teams. In addition, we'd like to assess the vulnerability of these small units.

Figure 8. Road Ahead (second two phases)



Next, we'd like to turn to a series of historical examples and ensure that EINSTein can reproduce in general the factors that have led to the changes in the Army's squad organization. Our goal here would be to gain additional confidence with the model and gather a set of examples we can use to illustrate the strengths of our modeling approach to the Marine Corps (at this point, we'll begin to provide them with preliminary results).

Finally, we need to stress one important aspect of this path. Remember that our goal in this process is to test EINSTein's ability to usefully depict squad-level combat. We expected that there would have to be some programming changes along the way. We've already identified some changes in weapons effects and scaling of the ranges in the model (to simulate grenades and machine guns), which have been addressed.

Below, we list some of the historical examples we'd like to explore with EINSTein. In each of these cases, there were clear decisions made about squad size and organization that were linked to changes in factors we should be able to simulate with EINSTein. For instance, in the first example, German squads at the end of WWI introduced a light machine gun (LMG) that gave them greater firepower out of their trenches and much greater success in the attack. Our list includes the following:

- WWI: German LMG (attacker's firepower increased, squads result)
- 1939: benefits of fire teams—mobility, mutual support, etc.
- WWII experience: three heterogeneous fire teams a problem
- Infantry conference: smaller basic unit, no individual fire teams
- Korea: two homogeneous fire teams
- Field tests (ROCID, IRUS)
  - — Weapons ratios
  - — Team sizes

For all but the first example, we'll look at the pros and cons of heterogeneous and homogeneous fire teams and the moves to and from the fire team as a tactical division within a squad. Particularly interesting is the experience in Korea: that squads acting alone were much more successful when they organized for fire and maneuver. For each of the examples, we expect that the main challenge will be capturing the physical characteristics of the environment in enough detail to exhibit the same findings as seen historically.

Finally, we hope to use EINSTein to examine some of the questions explored in the Army's field tests of the 1950s and 1960s. These tests focused primarily on varying squad sizes and organizations together with weapons distributions. They are in some ways easier to examine than the warfighting examples, as they attempted to somewhat control the effect of the environment.

EINSTein's results

This section summarizes our work with EINSTein. You'll remember that our study has two overarching goals. First, we wanted to work through the series of scenarios outlined in our road ahead to become familiar with the model and with EINSTein's ability to simulate small-unit ground-combat engagements. To this end, we'd outlined a series of increasingly complex scenarios based on our intuition and the data we'd obtained through our historical research. Second, after validating the model (assuming that all went well), we planned to use EINSTein as a comparative tool to examine a range of small unit organizations and their relevance to the Marine Corps future warfighting environments.

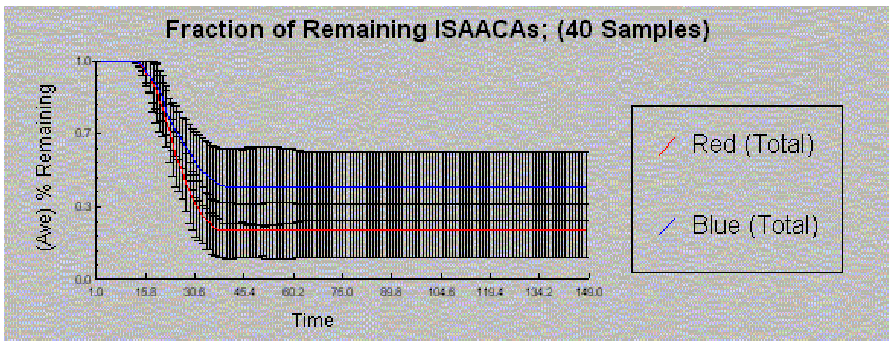
Here, we summarize our work using EINSTein to examine ground combat at the squad and fire team level. The roadmap for this section (and for the work contained herein) was presented earlier (see figures 7 and 8). As you'll see, we've completed part of our initial work with EINSTein: we've worked through simple squad engagements with varying sizes of squads, weapons effects, and introduced terrain. We've also begun examining some of the simple historical examples. Although some work needs to be done before we're ready to move forward with the model, all our work to date has been quite successful. Recently, we have expanded our work to begin looking at the organization within the squad.

While we haven't completed all the steps, we feel we have more than enough information to make some recommendations regarding further work in this area. We'll turn to these recommendations following this section. First, let's look at EINSTein's results.

Varying force size

First, let's examine some very simple runs we completed early in our work with EINSTein. The goal for these runs was to see how EINSTein treated squad engagements in the open. In these examples, we haven't included terrain, fire teams, multiple weapons, or any other complicating factors (we'll treat these in subsequent sections). Figure 9 shows the attrition results (the average attrition vs. time with the absolute deviation as error bars) for a run with two squads of 12 men—an even match. In the figure (and in most of the runs that follow), we've collected data over 40 runs with 150 time steps in each run.[1]

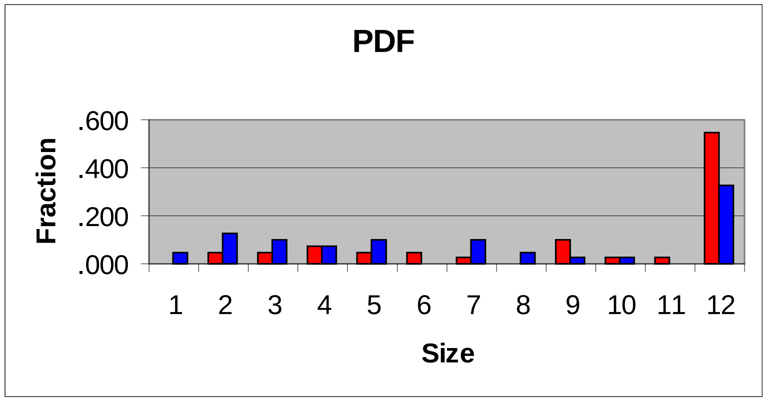
Figure 9. Attrition profile (12 v 12, rifles only)



As we can see, the attrition profile[2] for the squads is identical—evenly matched squads should on average have similar attrition profiles. Both squads come into the other's range at roughly 12 time steps (the range of the rifles used throughout our work is 55—the scaled range of a typical squad rifle), and the rate of attrition is roughly the same. After about 35 time steps, the squads break contact and withdraw to their respective goals with about 30% of their force intact (remember, they retreat when their squad size reaches roughly 50%). Figure 10 shows the associated probability distribution function (PDF).[3]

1. We found that with 40 runs the data converged and additional runs did not appreciably change the final outcome.
2. Figure 9, and many that follow, were made in EINSTein using the model's data collection routines.
3. EINSTein also saves additional attrition statistics for later data reduction. We won't go into details here; see [1] for further information.

Figure 10. Attrition fraction (12 v 12, rifles only)



This figure plots the attrition probability estimate versus squad size. As you can see, for these 40 runs, there is a slightly greater probability for Red to have a higher attrition than Blue (roughly .55 vs. .35 for n=12). But, examining figure 9, the average attrition level for both forces after the engagement is complete is roughly 30%. The descriptive statistics for the runs are shown in table 3.

Table 3. Attrition statistics (12 v 12, rifles only)

	Total attrition	Average attrition	Absolute deviation	Standard deviation	Variance
Red	372	9.30	3.09	3.57	12.78
Blue	275	6.88	3.73	4.21	17.75
Total	647	16.18	1.70	2.09	4.35
Samples	40				
Time/Sample	150				

As expected, all the data show the outcome of the engagement is a draw. But, before moving on, it's important to note that there is a rich range of outcomes contained in these results. As opposed to deterministic models, which treat an engagement with a predictive equation always yielding the same "answer," the squads in EINSTein exhibit a wide range of final outcomes. As figure 10 shows, there's a nonzero probability of Red or Blue having much lower attrition while inflicting severe casualties on the other squad.

While it's impossible to show here, observing the run unfolding on the computer is also quite insightful. In some cases, the Blue squad is the clear victor, killing all of the Red force and reaching the Red goal. In others, exactly the reverse occurs—the Red force kills all the Blue and reaches its goal. Yet in other runs, the two squads fight to a draw and withdraw to their respective goals with roughly 30% of their force remaining. All of these outcomes—for example, the nonzero probability that either force can win the engagement and kill all of the opposition—are captured by EINSTein. Remember too, that all these outcomes happen with the same input parameters.

In addition to attrition statistics, EINSTein also records center of mass positions (figure 11), which we've used to examine the point of greatest incursion into the enemy's territory, and neighbor counts (figure 12), which we've used to examine dispersing, along with various other MOEs (for a complete description, see [1]).

Figure 11. Center of mass positions (12 v 12, rifles only)

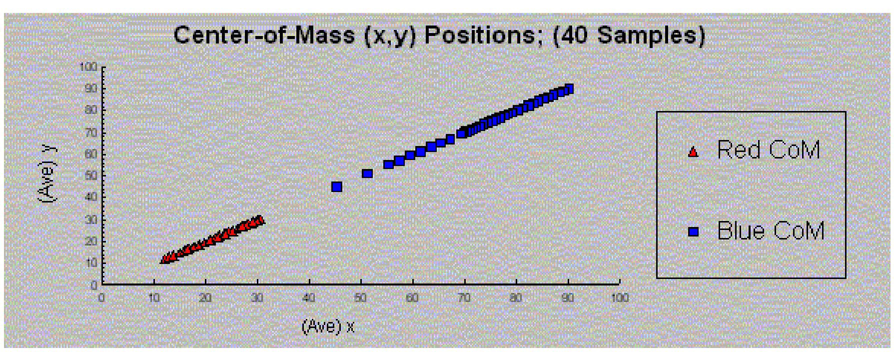
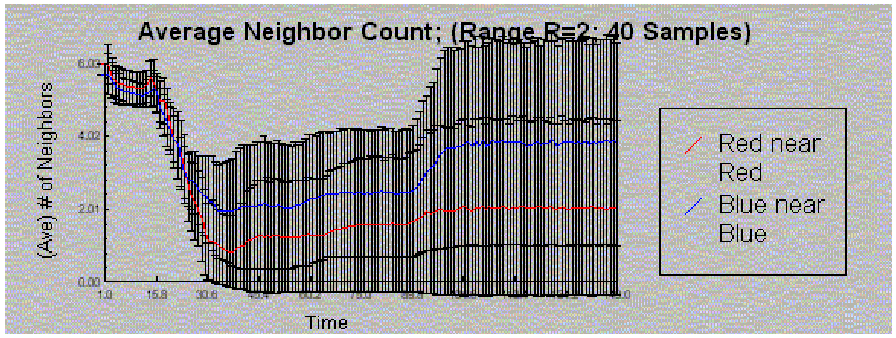


Figure 12. Neighbor count (12 v 12, rifles only)



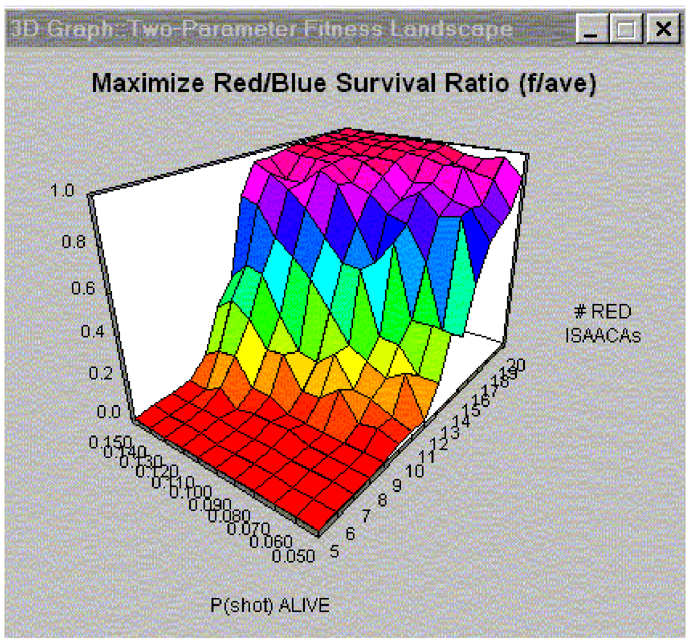
In line with the somewhat greater success of the Blue squad in this collection of 40 runs, figure 11 shows that Blue does make greater incursions in some of the runs into Red territory (as might be expected, given their slightly lower attrition). We can see that in none of the runs did the Blue force have sufficient strength to continue their advance to the Red goal. Examining figure 12, we see that on average Blue ends the engagement with a slightly higher number of friendly neighbors (approximately 4 or 30%), again in line with the attrition profiles.

These data are what we would expect to see for two evenly matched forces meeting with equal weapons and firepower on a battlefield free of terrain. The two forces degrade each other until they reach 50% of their initial manning, when they attempt to withdraw. In most cases (refer to figure 9), the squad is able to return to its goal with roughly 30% of its initial force. But, with a nonzero probability (roughly half the time, as shown in figure 10), one force wipes out the other (its strength remains above the 50% limit long enough for it to remain engaged and inflict 12 casualties). Finally, these data show some of the other MOEs we can use to analytically describe the outcomes of ground combat engagements.

After the simple meeting engagement shown above, we turned to some of EINSTein's more complex (and exciting) data-gathering capabilities. Our goal in doing a series of these early runs was to get a feeling for EINSTein's ability to capture the impact of changing force size. Our simple intuition is that a bigger squad should do better—but by how much?

Figure 13 illustrates EINSTein's fitness landscape mode. Here we've used the 3-D data manipulation capabilities of the model to show the trade-off between increasing force size and weapons accuracy. This mode gives us the ability to compare any two of EINSTein's variables. Unfortunately, this capability has yet to be enabled for the agent-specific weapons parameters (such as the grenades and machine guns) that we use in many of our subsequent runs. Thus, at this point, we've been unable to use this powerful feature in the work that we describe here.

Figure 13. Fitness landscape (varying Red numbers and Pk)



To create figure 13, we've varied the number of Red opponents (from 5 to 20) and their rifle Pk (from .05 to .15). The Blue force (the standard squad we used throughout our work) is fixed at 12 and has a rifle Pk of .1. Each data point contains 20 runs of 150 time steps. As one would expect, holding the rifle Pks at the same value (say, the .1 curve) we see that changes from 9 to 15 (roughly plus or minus 3 men) is where most of the attrition trade-off occurs. Beyond those limits, the Red force either overwhelms, or is overwhelmed by, the Blue force. Focusing on the Pks (at constant force size, take 12), we see that the same range of successful outcomes is captured by the full Pk distribution (.05 to .15). Thus, in this example, each entity is equivalent to a Pk change of roughly .017. While this is a simple example, it clearly shows the possibilities for using EINSTein in weapons effects analyses.

In the remainder of this section, in the interest of brevity, we'll present only those MOEs that illustrate our point. Now, let's turn to weapons effects.

Add grenades

Next, we focus on the impact of grenades in the squad and begin to see how we incorporate the effects of changing technology. This work is a particular subset of our general work on weapons effects. We've focused on grenades since they're a very important squad weapon. Further, we expect that these results would be important to a Marine looking to see that EINSTein captures all the richness of squad weapons (in a subsequent section, we'll show some results for machine gun). We'd expect to see that a squad with grenades inflicts more casualties than a squad without grenades (assuming all other things are equal). Further, we'd hope to see that a good squad tactic against an enemy equipped with grenades is to disperse its force.

In the first example, figure 14, we give the Blue squad two grenade launchers with a range of 35 and a Pk of .1 at the point of impact (see figure 3 for all the grenade statistics).

As we can see, the attrition statistics seem to be just the opposite of what we expected. The squad without grenades (the Red squad) actually inflicts higher casualties on the Blue squad. Figure 15 shows the attrition PDFs for the runs.

Figure 14. Attrition profile (12 v 12, blue grenades)

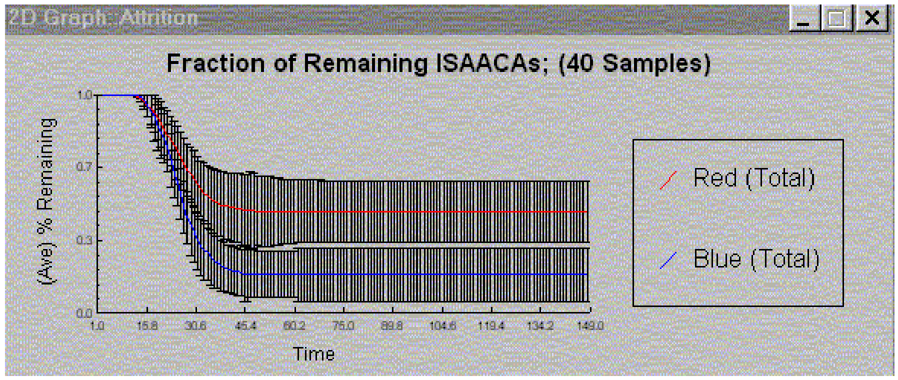
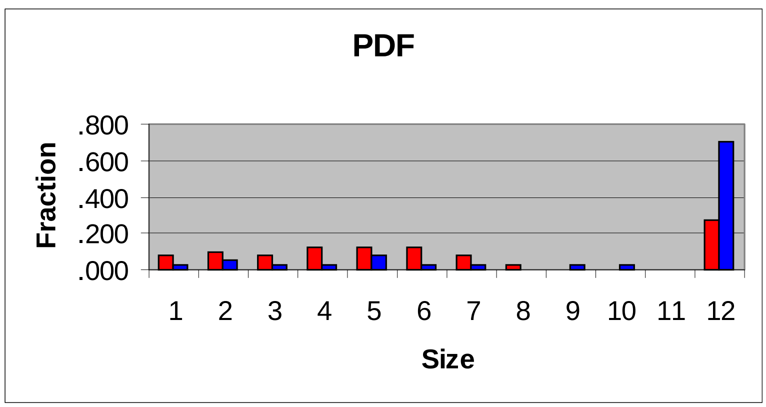


Figure 15. Attrition fraction (12 v 12, blue grenades)



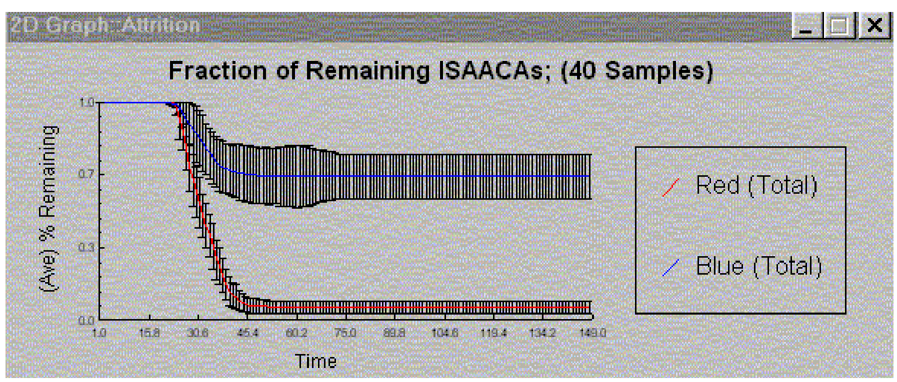
Just as in figure 14, the PDF confirms that the Red force has a higher probability of killing all the Blue (roughly .7 to .3). At the same time, its attrition probability function has a larger tail toward smaller attrition numbers. What is happening here?

It took us some time to understand the data, which at first appears counterintuitive. In fact, the answer is a simple effect of the weapons ranges, and the fact that EINSTein only allows each squad member to have one weapon. Thus, when a squad of 12 riflemen (the Red squad) faces a squad of 10 riflemen and 2 grenadiers (the Blue squad), the

Red squad has a much greater probability of inflicting the higher number of casualties *at the longer rifle range*. Note that there is a non-zero probability that the Blue squad does wipe out the Red squad, but grenades are not playing a large role in these engagements—for the most part, the engagements are at the longer rifle ranges. Remember that the range of the grenade launcher (35) is much less than the rifle range (55), and in most cases the engagement is already over before Blue can use his grenades. Examining the shots vs. hits, we see that only in 5 out of the 40 runs does Blue get within grenade range and employ the weapon (and in those 5 engagements they only inflict a few casualties). In the remaining 35 runs, the Blue squad's maximum firepower is generated when the 10 riflemen are firing simultaneously (versus 12 for the Red squad), and with about a .3 probability these 10 riflemen kill the entire Red squad (typically at longer than grenade ranges). The fact that the model did, after all, fall into line with our understanding was very encouraging.

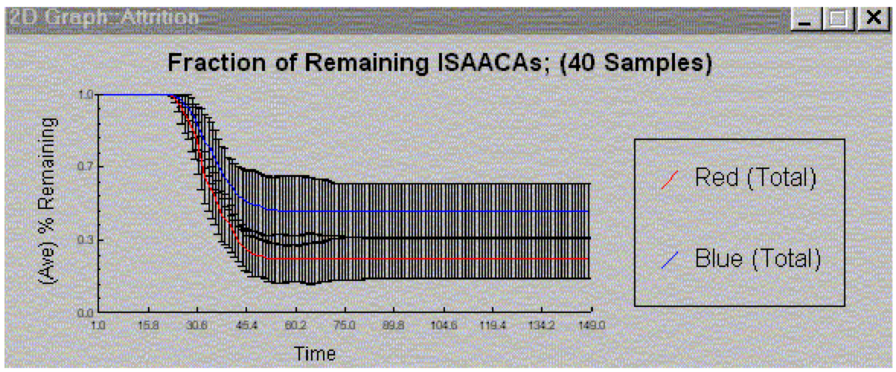
To try and get at the impact of grenades, we ran a set of runs where we limited the rifle range to 35 (same as the grenade range). Here, with the understanding we gained from the previous example, we **did** expect to see the impact of the grenade's greater firepower. Figure 16 shows the results of this engagement.

Figure 16. Attrition profile (12 v 12, Blue grenades & short rifles)



As expected, the impact of the grenades on the Red squad is severe. Although not included here, the PDF shows that the Red squad has a .8 probability of being totally wiped out by Blue, while the Blue squad has a .4 probability of only suffering 1 through 3 casualties (the probability of suffering 12 Blue casualties is only .3). Buoyed by these results, we wanted to see whether we could validate the tactic of dispersing to counter grenades. Figure 17 shows these runs.

Figure 17. Attrition profile (12 v 12, Blue grenades & short rifles, Red dispersed)



Comparing figure 17 to figure 16, we see that when the Red forces disperses, they stand a much better chance of successfully engaging and inflicting casualties on the Blue force. In the case where the Red forces did not disperse (figure 16), they were quickly decreased to a combat ineffective level and withdrew.

It's interesting to note that, while Red does much better in this example, the Blue grenades still have some impact (the two curves are almost distinct beyond the error bars). EINSTein generates dispersion among the entities by introducing a probability that entities are within a set of range rings from one another. This probability is factored into the move penalty along with all the other drivers of each moment (number of friends, number of enemies, etc.). When the forces disperse, there are still some instances where three or more entities come together and are a lucrative target for the Blue grenades—and Blue does exploit these instances. Watching the individual runs, you can see Red clumping, and Blue using its grenades.

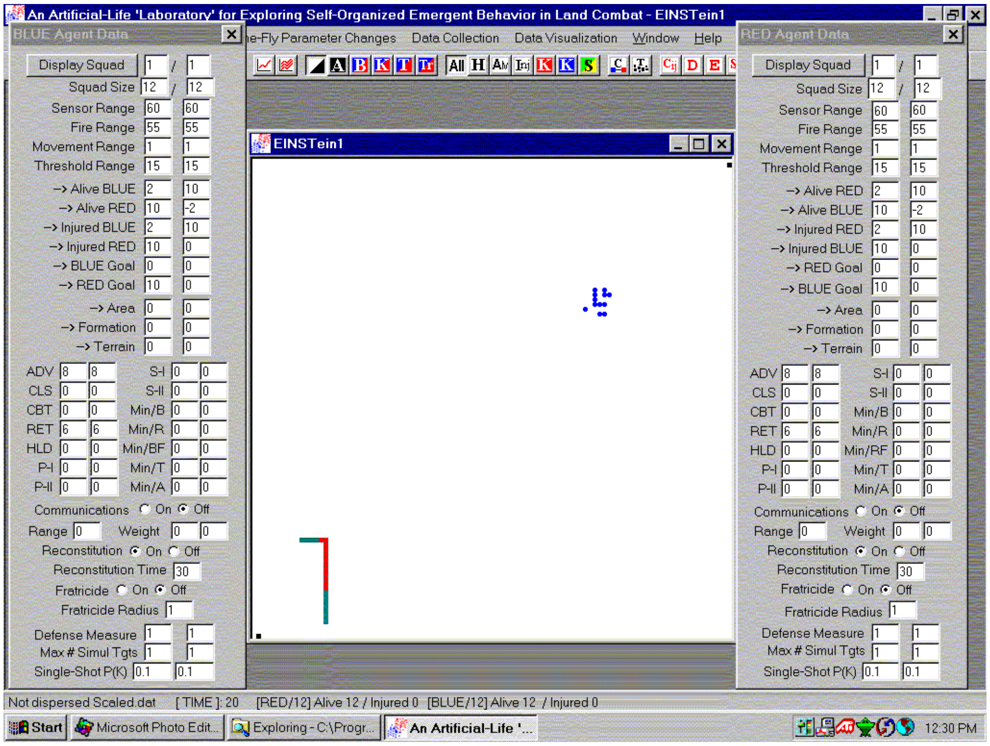
These examples meshed with our intuition (and increased our understanding) about the effects of grenades in squad engagements. Further, we feel they would mesh with a Marine's intuition of the expected results. We've seen that grenades, when employed, do generate more casualties than the rifle, but that with the proper tactics squads can severely limit their effects. Further, the counterintuitive results we saw for our first runs using grenades were understandable given the way EINSTein treats each entity's weapon. In reality, the 40mm grenade launcher is part of the M16 rifle and either weapon can be employed by the grenadier. On the whole, however, we feel that this approximation does not severely impact the model's results—at least not in the samples we've run to date.

Terrain effects

Next, we'll turn to some examples that incorporate terrain, another important factor in squad engagements (and key in many of the historical examples we've already discussed). Again, the goal of this series of runs was to continue to develop our knowledge about how EINSTein works, and to illustrate some simple, well-known effects of terrain on squad engagements. Figure 18 shows an EINSTein screen shot with some simple terrain for the Red squad—our goal was to recreate a berm.

As you can see, the Red force has arrayed themselves behind the berm and are waiting for the Blue to advance. EINSTein allows the user to define terrain features (both solid and permeable) and the effects the various types of terrain has on the entities. Here the berm (a permeable terrain) decreases Red's movement range (here to zero, fixing them in the terrain), and also decreases its visibility to 15% of normal (we choose this degradation in visibility to approximate the head and shoulders—about 15% of the body—shown by a dug-in force). Thus, a Blue entity has only a 15% chance of seeing each of the Red entities when they come within Blue's sensor range (versus 100% for entities out in the open). Remember, that before an entity can engage another he must successfully see and target him.

Figure 18. Simple terrain—a Red berm



So, as Blue comes into Red's rifle range, it is targeted and engaged with a much higher probability than the dug-in Red force—1 versus .15 (Both squads have the same weapons—rifles with identical Pk and range.) Figure 19 shows the attrition curves for this engagement, and figure 20 shows the attrition PDFs.

As you can see, the attrition of the attacking force (Blue) is substantially higher (and much steeper) than the attrition of the defending force (Red). The only reason that the attackers are able to survive with some of their force intact is that they are able to get out of range (the squad drops below the combat effective threshold of 50% and attempts to withdraw) and Red cannot pursue. As an aside, this ability to retreat is important in the believability of the model—faced with mounting attrition, squads of real Marines will fall back and regroup.

Figure 19. Attrition profile (12 v 12, Red behind berm)

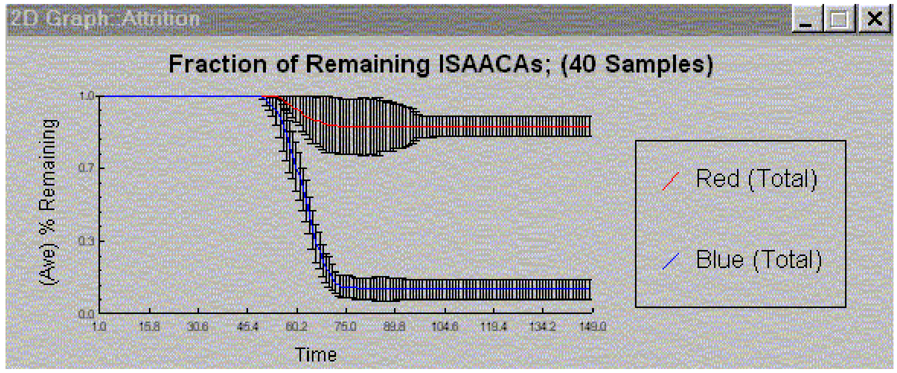
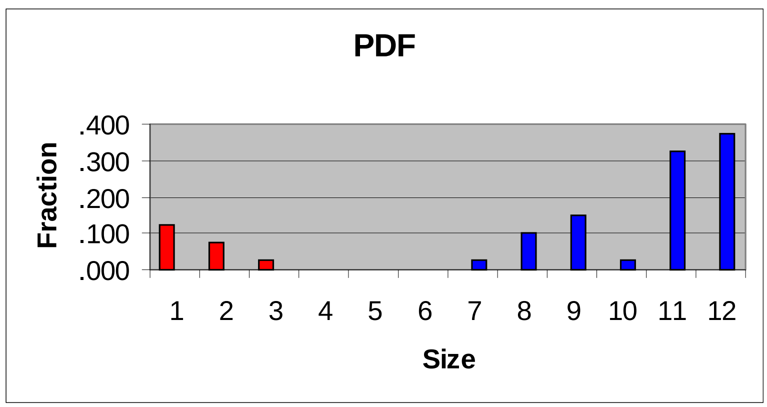


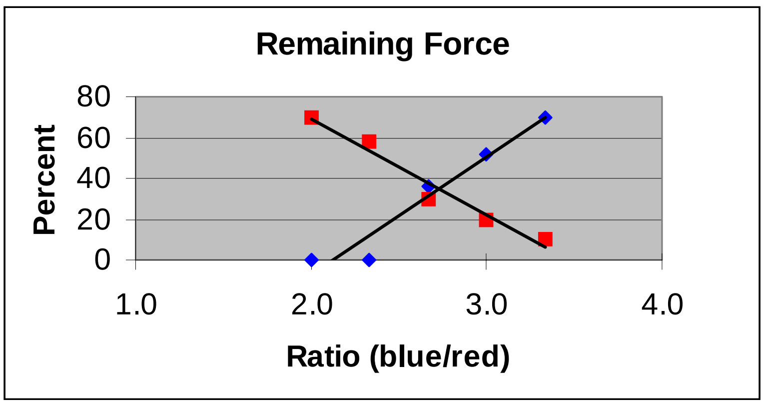
Figure 20. Attrition fraction (12 v 12, Red behind berm)



In our example, Red suffers only a few casualties. In most cases the Red force remains at full strength after the engagement—the probability of zero Red casualties is roughly .8. This result is entirely in line with our (and, we'd argue, with a typical Marine's) intuition. Throughout history, the defending force has had the advantage (all other factors being equal) against an attacking force that must traverse open ground. One might ask how large a Blue force must be in order to overcome the advantage of the red's terrain. Our next set of runs examined this very issue. Our goal was to see whether the model would bear out the traditional “rule of thumb” that attackers need a 3:1 force ratio against a defended position.[4]

Figure 21 shows the results of these runs (in the interest of space, we haven’t presented the individual attrition curves and PDFs). In these runs, we’ve gradually increased the Blue force from 12 to 40 men and used attrition as our MOE. Figure 21 plots the percentage of the original force at the end of the engagement (t=150) versus the attackers-to-defenders ratio (the lines are simple fits to the data to guide the eye).

Figure 21. Impact of squad size in the attack

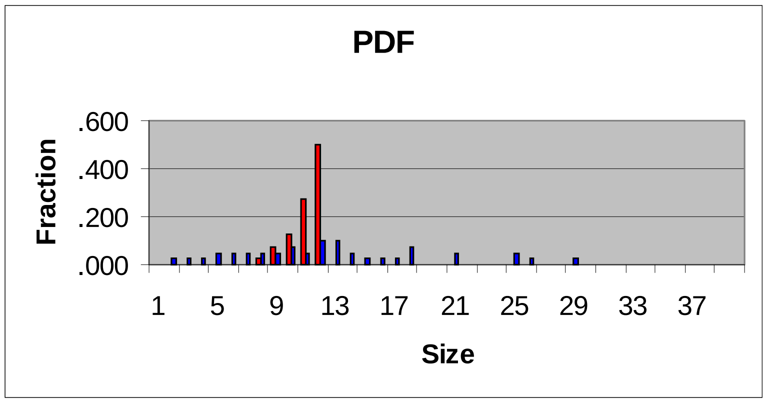


As you can see, the Blue force doesn’t start surviving in large numbers until its force ratio approaches 2.5 (roughly 30 Blue versus 12 Red). Then, the percentage of the Blue force remaining after the engagement rises quickly as the Blue force approaches three times the number of defenders—the curves cross at about 2.8:1. At the same time, the Red remaining at the end of the engagement decreases

4. While we were looking for a 3:1 success ratio, it’s true that under other circumstances other ratios might be more appropriate. Thus, again we’re using EINSTein to check our intuition and expand our horizons about ground combat.

steadily, and by the time Blue outnumber Red by 3:1, has decreased to only 20%—a clear victory. This result is very much in line with our intuition, and we were very happy with EINSTein's ability to duplicate this empirical rule. Figure 22 shows the attrition PDFs for the run where 40 Blue attack 12 Red.

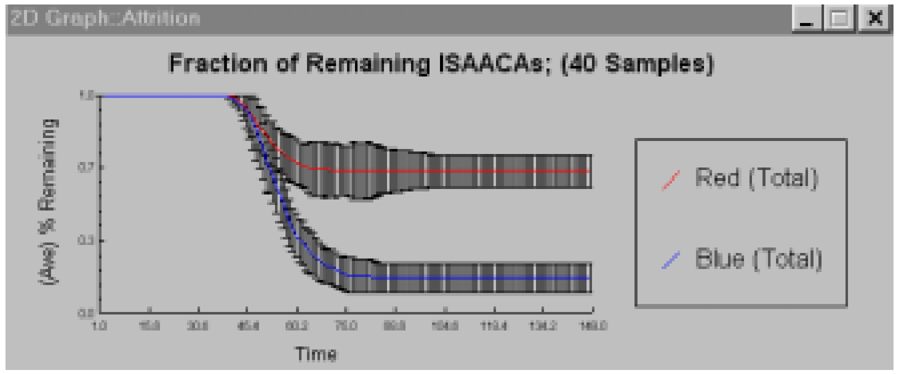
Figure 22. Attrition fraction (40 vs. 12, Red behind berm)



Here we see that the highest Red attrition probability (.9) is for a attrition of over 80% of the Red force (10, 11, or 12 casualties). At the same time, the Blue forces has a .4 probability of losing between 1 and 10 men, and an .85 probability of losing between 1 and 20 men. In other words, Blue has an 85% chance of surviving with half their force intact.

After examining the impact of increasing the number of attackers, we turned to a number of runs that vary the weapons set of the attacking force (looking for the trade-off between equipment and personnel). Without getting into the myriad of details, we found that equipping the Blue force with grenades (we made runs with both two and four launchers) did not have as great an impact as we expected, even when we restricted the range of the rifles to 35. Figure 23 shows these results.

Figure 23. Attrition profile (12 v 12, Blue grenades, Red behind berm)



Comparing these data to a run with rifles only (figure 19), we expected to see a greater enhancement of Blue's success (due to the greater firepower of the grenade). While we see that Blue does kill Red in higher numbers (the curves above are similar to the case where 24 Blue attack 12 Red), we found that Blue used the grenades less frequently (compared to forces meeting in the open) than we expected.

After some additional data collection, we found that the limited use of the grenades is solely due to the inability of the Blue force to pick out Red targets behind the berm. Remember that terrain degrades Blue's ability to locate targets with all weapons, and a Red entity behind the berm is only 15% as visible as a Red entity in the open. Grenades, which probably would be fired against the berm rather than at a group of entities behind the berm (in a suppressive role), do not seem to be used as effectively by the Blue force as we might expect. Surely, we'd see more grenades fired if the entities could target the terrain rather than the individuals. Another way of looking at this problem is that, at this point, EINSTein treats weapons as tools that can only kill the enemy, rather than as tools that can suppress the enemy (firing in the direction of the enemy without a specific target) and degrade their ability to return fire. Whether not fully capturing these effects will become important in our work remains to be seen.

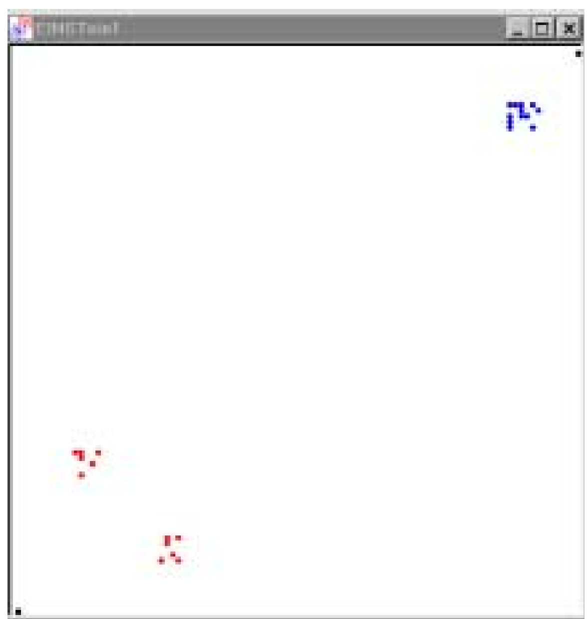
On the other hand, it is interesting to note that the addition of two grenadiers (into a force of 12) is roughly equivalent to adding an additional 12 riflemen (at least when we use a shorter-range rifle). While not the subject of our analysis, this trade-off again points to an interesting weapons application for EINSTein (a line of research we have not yet pursued).

Next we turn to our latest work, the implementation of fire teams in EINSTein.

Impact of fire teams

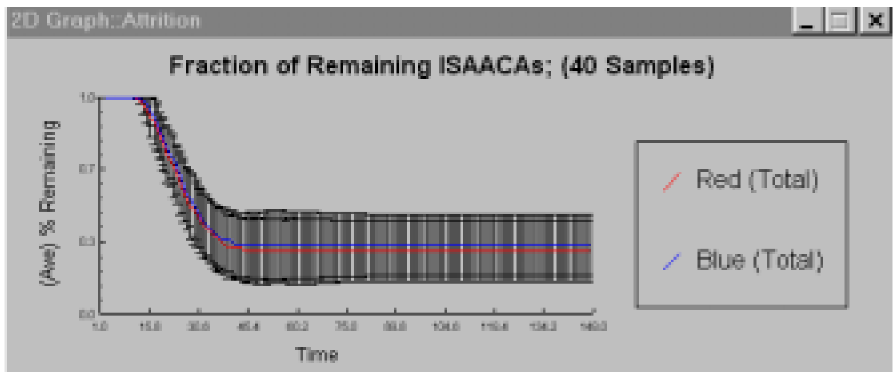
Our first implementation of fire teams was to divide the 12-man squad into two homogeneous fire teams of six men. We gave the Red squad two fire teams and kept the Blue squad as a single unit. Figure 24 shows the initial distribution of forces for these runs. As you can see, the two Red teams are separated—they retain this separation throughout their engagement (the two fire teams do not communicate and are not influenced by entities in the other fire team).

Figure 24. Two fire teams—initial positions (12 v 12, rifles only)



A priori, we doubted that two fire teams in the open would do any better than one large squad. Remember that in our historical research, we examined the Army's move away from fire teams in WWII. In many of its engagements in Europe—on open ground—the Army found that operating in teams gave no advantage. The point is that, in an engagement in the open, the simple firepower metrics hold. Thus, we didn't expected that EINSTein would show any difference. Figure 25 shows the attrition profiles.

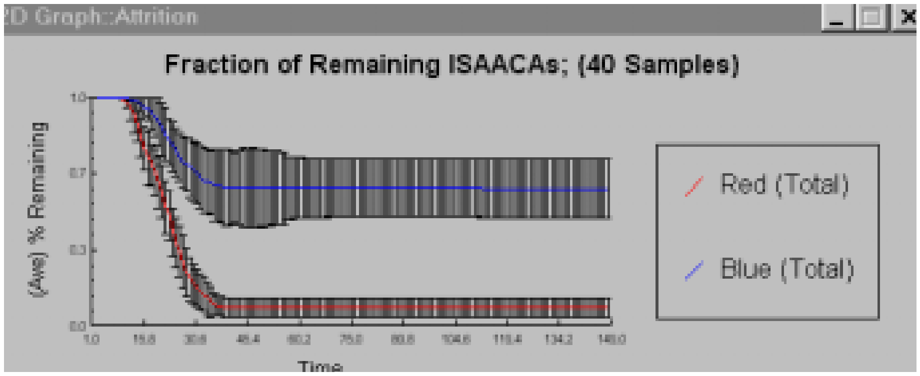
Figure 25. Attrition profile (two Red fire teams)



As expected, fire teams gain the Red squad nothing in the engagement. Both squads are depleted at the same rate and reach a strength of roughly 30% by the time they've broken off the attack. With equal numbers of the same weapons, the firefight has the simple probabilistic outcome.

Next, we looked at an example where the two fire teams advance in a staggered formation. Here, one fire team engages the Blue force before the other (one Red team is in front of the other by a short distance). In this case, the leading fire team is severely outgunned—by 12 to six—and is quickly depleted. Then, the second fire team comes into range and faces a similar fate as that of their squadmates. Figure 26 shows the attrition profiles for this situation.

Figure 26. Attrition profile (two Red fire teams staggered)



Again, we're seeing some of the subtleties of ground combat engagements at the squad and fire team level. As we've already discussed, EINSTein doesn't allow for suppressive fire (at least at this time[5]); we see none of the pinning down that might occur with the leading fire team and the maneuvering of the second fire team (granted, there's no terrain here to maneuver around) to gain position against the squad without fire teams. Our most recent work, which is beginning to explore fire teams and terrain together, appears very similar to the runs with terrain and without fire teams. However, we have not yet done enough work in this area to come to any conclusions, or to include these preliminary results here.

Historical example: HMG / LMG

Here we'll present one final example, the first historical scenario we tried to recreate using EINSTein. Based on the success we'd been

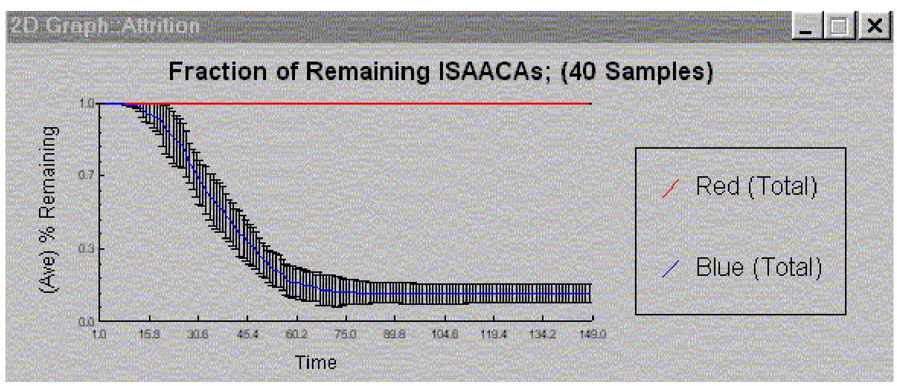
5. Current modifications to EINSTein that support more entity states (beside alive and injured) may allow us to define states such as "suppressed," and remedy this situation. We also should stress that we don't know yet whether this lack of suppressive fires is important to our overall results, or is simply a higher-order behavior that isn't important to our outcomes. We suspect the former, but need to wait for more data before drawing the conclusion.

having with our preliminary runs, we were anxious to see how EINSTein did with a somewhat more complicated example.

Recall from our historical overview, that an important development at the end of WWI was the German's fielding of a light machine gun (LMG). Until then, the only machine guns in use had been heavy machine guns that, because of their weight, could only be used in the defense (they were too heavy to be moved forward quickly with units in the attack). Employing their LMG, German forces in the attack were much more successful than units without the machine gun. They quickly adopted the weapon as a squad asset (other counties quickly followed suit).

To explore this example, we expanded our work with a dug-in Red force (see above). For the base case, we used the 12 v 12 example shown in figures 19 and 20 and gave the defending force two heavy machine guns (a higher rate of fire weapon, with a longer range, and a 50% lower Pk than the rifle). Figure 27 shows the impact of this weapon on the engagement.

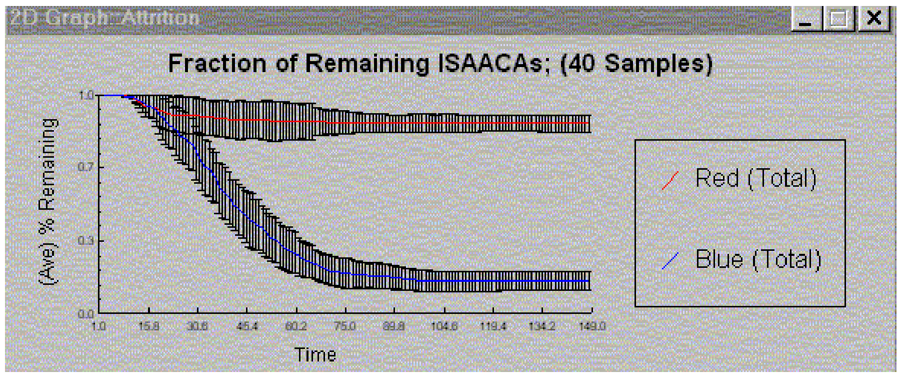
Figure 27. Attrition profile (HMG in the defense)



As you can see, the longer range of the HMG couple with its ability to engage multiple targets exacts a heavy toll on the attackers. The PDF is what you would expect with 75% of Blue attrition from 10 through 12 men, and zero probability of any Red attrition.

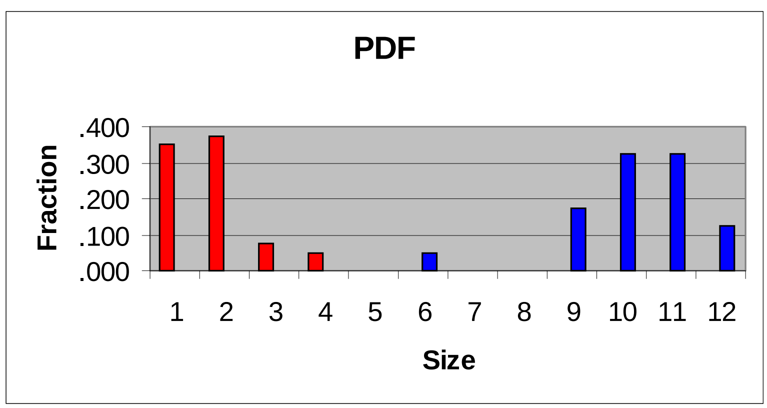
Next, we wanted to simulate the German's introduction of the LMG. Here we gave the Blue squad two machine guns (with the same weapons parameters as Red's HMG). Figure 28 shows what these two LMGs do for the attackers.

Figure 28. Attrition profile (LMG in the attack)



While Blue still suffers heavy losses, it is able to effectively target some of the Red forces. As we can see, the impact is relatively small, but we do see some attrition—figure 29 shows the PDF.

Figure 29. Attrition fraction (HMG and LMG)



Although we won't show it here, adding two more LMGs does increase Blue's effectiveness against the dug-in Red—not to the point of winning, but the trend is in the right direction. Again, we see that this example may suffer from the lack of suppressive fire, which is the same problem as our terrain example (the Blue force with two grenade launchers) has. As we mentioned above, we don't yet know how important suppressive effects are to squad engagements. Conversations with Marines haven't convinced us either that we're approximating too much away and should include suppressive effects, or that we don't need to include suppressive fire. Thus, we continue ahead, with this question remaining to be settled with future work.

Summary of results

In the sections above, we've explored much of our preliminary work using EINSTein to simulate squad and fire team engagements. Comparing these results to the road ahead we outlined in figures 7 and 8, one can see that while we've made some headway, we're still working to understand how well EINSTein captures the basics of squad interactions.

At this point, we're satisfied with how well the simulation is working. We're just beginning to look at the impact of terrain and fire team organization, but nothing we've seen up to this point leads us to believe that the additional complexity inherent in these systems won't be captured in the model.

As we alluded to earlier, it's unclear to us how important the approximations in the model really are, and how much they impact the results. Only time and continued work with EINSTein will tell. For example, we commented that not capturing suppressive fires (an approximation that may soon be incorporated into the model) was intuitively disturbing, but we remain unsure how important that approximation really becomes from the standpoint of accuracy of the results. Remember, any model is by nature an approximation of reality, and may or may not capture enough of the situation. We remain anxious to see just how closely EINSTein captures the nuances of ground combat, and how important these nuances are to the overall questions we're asking.

Finally, while we've explored a number of scenarios that examine various aspects of the questions we felt were important in determining squad size and organization, much remains to be done in this area and many other scenarios remain for further exploration. In the examples we've shown, we saw some of the other areas (for example, weapons effects) that appear to be exciting areas of research for continued work with EINSTein.

Conclusions and recommendations

This section summarizes the conclusions from our historical overview, our review of ground combat models, and our work with EINSTein. We also provide some recommendations for future work on the ground combat study, using EINSTein to simulate squad and fire team engagements.

In our review of squad and fire team development, we found a wealth of data on changes in Army squads since WWI. At the same time, we observed that the Marine Corps' squad has remained relatively stable over the same period of time. While this difference was not fully explained in our historical research (we suspect it is a function of the different environments—tangible factors—faced by the two services), we did find that most of the changes in squad size and organization can be attributed to the following key drivers: firepower, resiliency, maneuverability, and mobility. Many of the changes in firepower throughout the period of interest were due to changes in technology—a major driver of change. With respect to maneuverability and mobility, the historical examples show many cases in which terrain and internal organization affected the squad and how these variables contributed to change. Finally, we saw how the size of the squad contributed to resiliency and how historically squads became combat ineffective when their numbers dropped below a certain threshold.

Based on our review of the modeling world, with an eye to small-unit ground-combat engagements, we quickly concluded that EINSTein was the only model available that could begin to capture the richness of interactions we required at the small-unit end of the spectrum. From the impact of terrain, through the variation in squad weapons, and changes in size and organization of the squad, EINSTein seemed to capture enough of the details, while remaining user-friendly. Although we recognized its capabilities, we understood that we were using the model in a region that wasn't intended when EINSTein was developed. And, while we could see no show stoppers, we outlined a series of tests—intuitive and historically based—that would give us confidence in the model when we used it to examine USMC squads and fire teams on future battlefields.

Our work with EINSTein has explored firepower, squad size and organization, and the impact of terrain on ground combat engagements. In other words, we've been able to sample most of the factors we've seen historically as being important to the development of the squad. Throughout this work, much has been in line with our intuition. We've come away from our analysis with confidence that, so far, EINSTein has been able to capture the important aspects of the engagements and, in so doing, has shown its ability to confirm our intuition, or get the same "answer" as the one we've seen historically.

But, we've only scratched the surface, and much remains to be done to ensure that EINSTein works in this size region, and that it can help the Marine Corps. Thus, we present the following recommendations:

- First, continue the USMC Ground Combat Study with CNA-initiated funds. As we continue to work through our roadmap and begin to explore the more complicated historical examples and various scenarios of interest to the Marine Corps, we will need to expand our audience to include Marines, at Quantico and elsewhere, who are familiar with the issues we're exploring and can provide constructive feedback.

- Second, begin to explore the capabilities of EINSTein in the area of weapons effects. In our preliminary conversations with Marines, the ability to trade off weapons effects has struck a chord. Again, it's important to begin to include subject matter experts at Quantico (SYSCOM and MCWL) who look at these issues day to day.

- Finally, continue our partnership with the EINSTein development team. Without the team's hard work throughout this analysis, we would have been unable to carry out much of the work presented in this report. For example, the modification to the model expanding the squad's weapons set allowed us to look at the impact of grenades and machine guns, and pointed out the rich analytical capabilities examining weapons effects. That said, there are still areas where the model can be expanded to capture other important squad and fire team characteristics. As we work through the remaining steps in our roadmap, we believe that the model will require modifications in other areas.

In summary, while we remain confident of EINSTein's ability to simulate ground combat, there's still much work to be done before we're ready to ask the Marine Corps to support this work.

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