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THESIS

THE EFFECTS OF POSTURE, BODY ARMOR, AND OTHER EQUIPMENT ON RIFLEMAN LETHALITY

by

Gary R. Kramlich II

June 2005

Thesis Advisor:	Thomas W. Lucas
Second Reader:	Richard Spainhour

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13. ABSTRACT (maximum 200 words)

How does body armor and posture affect Soldier marksmanship? The Interceptor Body Armor (IBA) has significantly improved Soldier combat survivability, but in what ways does it change rifleman lethality? Moreover, can we model these effects so as to develop better tactics and operational plans? This study quantifies the effects of Soldier equipment on lethality through multi-factor logistic regression using data from range experiments with the 1st Brigade, 1st Infantry Division (Mechanized), at Fort Riley, Kansas.

The designed experiment of this study estimates the probability of a qualified US rifleman hitting a human target. It uses the rifleman's equipment, posture, Military Occupational Specialty (MOS), and experience along with the target's distance, time exposure and silhouette presentation as input factors. The resulting family of mathematical models provides a Probability of Hit prediction tailored to a shooter-target scenario.

The study shows that for targets closer than 150 meters, Soldiers shot better while wearing body armor than they did without. Body armor had a negative effect for targets farther than 200 meters, and this could significantly impact the employment of the Squad Designated Marksman. The study also shows that the kneeling posture is an effective technique and recommends standardized training on this method of firing.

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THE EFFECTS OF POSTURE, BODY ARMOR, AND OTHER EQUIPMENT ON RIFLEMAN LETHALITY

Gary R. Kramlich II
Captain, United States Army
B.S., United States Military Academy, 1996

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June 2005**

Author: Gary R. Kramlich

Approved by: Thomas W. Lucas
Thesis Advisor

Richard Spainhour
Co-Advisor

James Eagle
Chairman, Department of Operations Research

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LIST OF ACRONYMS AND ABBREVIATIONS

ACH	Advance Combat Helmet
APFT	Army Physical Fitness Test
CCO	Close Combat Optics
COMBAT XXI	Combined Arms Analysis Tool for the 21st Century
CPQR	Combat Pistol Qualification Range
DoD	Department of Defense
EST	Engagement Skills Trainer
FM	Field Manual
GL	Grenade Launcher
HL	Hosmer-Lemeshow
HQDA	Headquarters, Department of the Army
IBA	Interceptor Body Armor
IWARS	Infantry Warrior Simulation
MAWG	Modeling and Analysis Working Group
MOLLE	MOdular Lightweight Load-carrying Equipment
MWS	Modular Weapon System
NPS	Naval Postgraduate School
NVG	Night Vision Goggles
OneSAF	One Semi-Autonomous Forces
OR	Operational Research
PAM	Pamphlet
PASGT	Personal Armor System Ground Troop
PEO	Program Executive Office
PH	Probability of Hit
PMI	Pre-Marksmanship Instruction
QRF	Qualification Record Fire
SaaS	Soldier as a System
SAPI	Small Arms Protective Inserts

SDM	Squad Designated Marksman
TRAC	TRADOC Analysis Center
TRADOC	US Army Training and Doctrine Command

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I am indebted to a great number of people for the patience, time and support they provided. First and foremost, I want to recognize Dr. Tom Lucas, my thesis advisor, and MAJ Rich Spainhour, second reader. It was their guidance and expertise that shaped my ideas into the report that follows. Their interest in Soldier issues and concern in practical findings kept the study grounded and relevant to current operations.

The initial structure of the design of experiment and data collection was the result of working with the exceptional folks at the Natick Soldier Center Modeling and Analysis Team, and especially Mr. Michael Statkus. It was their previous work that formed a template for the experiment and made the experiment fruitful.

The study would not have data if not for the hard work and willingness of the Iron Rangers of 1st Battalion, 16th Infantry (Mechanized). The outstanding Soldiers of this battalion, under the leadership of Lieutenant Colonel Thomas S. Hollis, Captain John Hill and Second Lieutenant Darryl Hill, were both the focus and the critical component of this study. On the rifle range, they consistently displayed the same dedication and fortitude to training that made them successful in combat. It was an honor to work with them.

I could not have produced the statistical analysis without the instruction of Dr. Lynn Whitaker, Dr. Sam Buttrey, and Dr. Susan Sanchez. Their technical expertise saved many hours of computational work. Colonel (Retired) Ed Lesnowicz and Colonel Saverio Manago provided terrific input that kept the study's language understandable, and I appreciate their help and mentorship.

Lastly, it was my beautiful wife Sandra Roldan and daughter Georgia that gave me the courage and spirit to tackle this task in the first place. Their love and understanding are my inspiration.

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EXECUTIVE SUMMARY

A.   BACKGROUND AND MOTIVATION

The Global War on Terrorism has reintroduced the rifleman as the predominate offensive system against an elusive threat. To improve the performance of the individual rifleman, the US Army introduced an initiative called Soldier as a System (SaaS) / Soldier Enhancement Program. A key component in improving Soldier systems is modeling and simulation. The US Army's Training and Doctrine Command Analysis Center – (TRAC) listed several knowledge voids in current Soldier modeling and simulation capabilities (Solider MAWG, 2004). One of these areas is "to represent the effects of different firing positions on engagement accuracy." This gap became the focus of the study—quantify the effects of posture, body armor and other individual equipment on rifleman lethality.

The study addresses two specific questions regarding equipment and posture. First, how does body armor affect a rifleman's probability of hit, and how does this affect the employment of the Squad Designated Marksman? Second, how effective are the Kneeling and Standing postures compared to the standard Foxhole and Prone postures, and is there a potential benefit in conducting standardized training on these postures?

The analysis uses data from experiments conducted on an automated Qualification Record Fire range at Fort Riley, Kansas. The experiment consisted of Soldiers firing qualification tables using different postures while either wearing or not wearing Interceptor Body Armor (IBA). The experiment covered four different firing postures. The two primary postures were the Foxhole Supported Position and the Prone Unsupported Position. The two alternate postures were the Kneeling Position and the Standing Position. The study used a total of 10 different firing scenarios, both day and night. Each of the 29,005 observations from 466 soldiers contains over 40 possible explanatory variables.

B.   EFFECTS OF BODY ARMOR

As seen in Figure 1, in target ranges from 50 to 150 meters, those Soldiers wearing IBA actually shoot better than those without IBA.   This advantage, however, diminishes as the distance increases.   At 200 meters, riflemen not wearing IBA shoot better than those wearing it. The negative effect of IBA at longer ranges may have impacts on the Squad Designated Marksman (SDM). The data suggests that the SDM might be more effective without full body armor.

PROBABILITY OF HIT BY RANGE
By Body Armor - Day Prone Tables Only
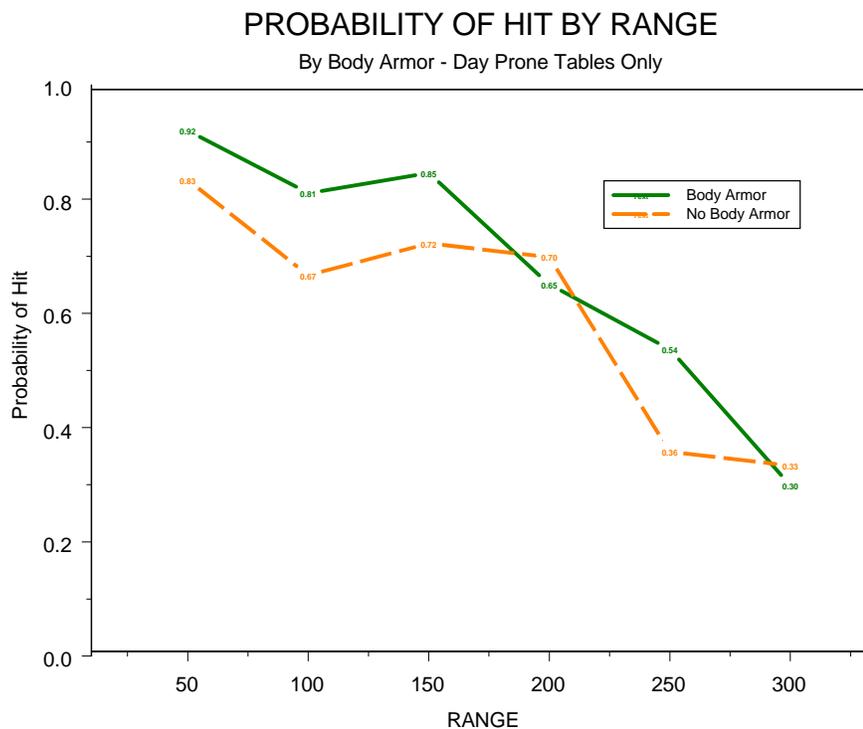
Figure 1.   PH by Range and Body Armor Type

C.   PROBABILITY OF HIT BY FIRING POSTURE

As seen in Figure 2, there is a marked difference in the Probabilities of Hit between postures. The more stable postures, such as Foxhole Supported, are inherently more accurate than an unstable position, such as Standing or Kneeling. The chart shows the same decrease in PH as the target distance increases. The Kneeling posture, while less accurate than the traditional Prone

or Foxhole postures, is still an effective posture at longer ranges. The Soldiers conducting the experiment had no formal training in this posture, and it is very likely the PH for Kneeling would improve with formal training. The Standing posture, in contrast, has a precipitous drop in PH in the short ranges and does not look to be effective at ranges beyond 50 meters.
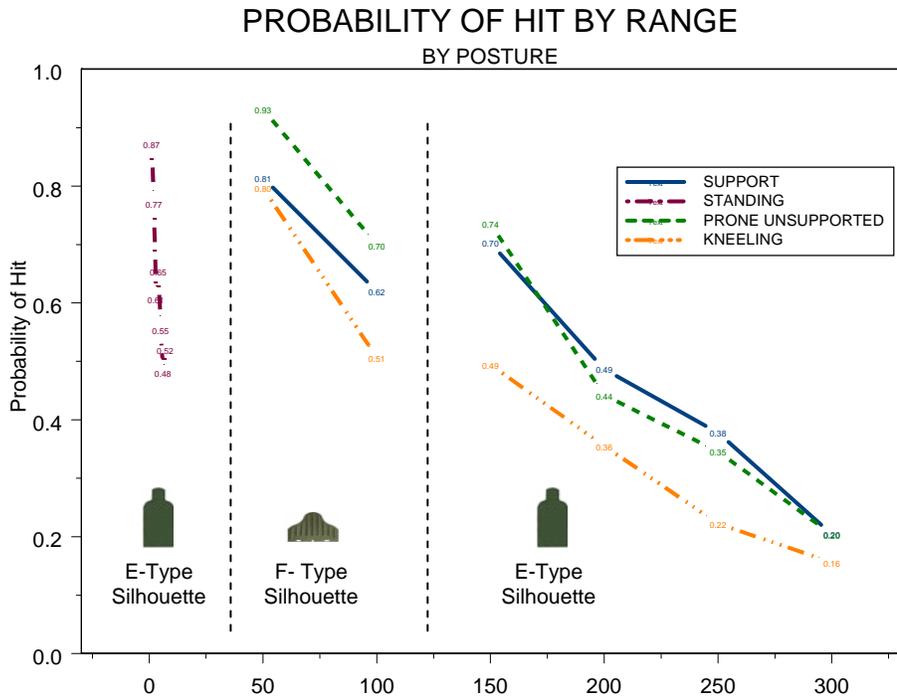
Figure 2.   Probability of Hit by Posture

D.   MODELING PROBABILITY OF HIT

The study constructs a family of models that estimates a rifleman's Probability of Hit for a specific target scenario. To predict the Probability of Hit, multivariate logistic regression models use interactions between shooter's equipment, posture, rank, and experience; the target size and distance; in addition to environmental conditions. The result is a family of models containing from 1 to 160 predictor variables that account for various levels of variation in the data. These models not only quantify the interactions of posture and equipment,

but can be useful in larger simulations to demonstrate how those interactions may impact unit effectiveness.

E.   IMPACTS OF FINDINGS

1. Body Armor and the Squad Designated Marksman

The data suggest that at ranges beyond 200 meters, current body armor has a negative impact on SDM lethality.   Methods of correcting this include modifying the equipment and/or the marksmanship training.   This study recommends modifying the IBA to better stabilize the rifle buttstock, and recommends formal training while wearing body armory.   In either case, the impact of body armor on SDM effectiveness warrants further research.

2. Kneeling Posture as an Alternate Posture

Soldiers firing the Kneeling posture have a Probability of Hit that is less than but comparable to the Prone or Foxhole postures.   There is potential that the Kneeling posture, when fully trained, may offer equal lethality with better mobility over traditionally trained postures.   The study recommends incorporating the Kneeling posture into standard rifle qualification.   The study found that Soldiers are using Kneeling posture in actual combat, but they rarely train on this posture prior to deployment.   The subject deserves more research on developing Kneeling marksmanship and how this training translates into rifle qualification standards.

3. Other Findings

The study finds no significant difference between the standard ironsight and the M68 Close Combat Optic.   The data show no statistical differences between the M16 and M4 weapons.   The M4 is less accurate at all ranges. These differences may or may not be practically significant.   Additionally, the study finds no significant difference in the Probability of Hit for Combat Arms and Combat Support or Service Support MOSs.   Lastly, the ACH helmet appears to have negative effects on Probability of Hit, but the findings are heavily dependent on other factors.

I. INTRODUCTION

Soldiers remain the centerpiece of our formations and they are the most-deployed system in this global war on terrorism. As such, we must continue to properly equip and train them for the difficult mission they face. To better accomplish this task, the Army has initiated two overarching steps—Soldier as a System (SaaS) and the Rapid Fielding Initiative (RFI)

(Durr and Liberstat, 2004)

This chapter

- Describes the origins of the study.
- Discusses how this study supports current simulation development.
- Identifies possible benefits provided by the study.
- Describes the general structure of the thesis.

A.   OVERVIEW

Current operations in Southwest Asia have changed both the strategy and focus of the United States military. Enemy tactics and terrain reintroduced the rifleman as the predominate system of force against an elusive terrorist threat. To improve the performance of the individual rifleman, the US Army introduced an initiative called Soldier as a System (SaaS) / Soldier Enhancement Program. This initiative has the goal "to improve the lethality, survivability, command and control, mobility, and sustainability for all Soldiers…which can be adopted and provided to Soldiers in three years or less." (PEO Soldier, 2005) A key component in improving Soldier systems is modeling and simulation.

Modeling the effects of individual Soldiers in combat is an extremely complex and arduous task. The US Department of Defense (DoD) has used complex models and simulations for decades to form strategy and policy, but modeling the individual combatant is relatively new. Until recently, modeling the Soldier and his effects in large-scale models were either beyond computational capabilities or determined to be negligible. Several current Department of the

Army simulations—One Semi-Autonomous Forces (OneSAF), Combined Arms Analysis Tool for the 21st Century (COMBAT XXI), and Infantry Warrior Simulation (IWARS)—are in the process of building high resolution simulations that include individual Soldier entities. Simulations such as these seek not only to demonstrate the effects of individual combatants, but also to improve the tactics for current and future combat.

B.   BACKGROUND AND MOTIVATION

1.   Knowledge Gaps

The US Army's Training and Doctrine Command Analysis Center – (TRAC), one of this study's sponsors, is the proponent of the Soldier Modeling and Analysis Working Group (MAWG), a cross agency organization of TRAC that identifies "future development and use of modeling and simulation (M&S) to support Soldier and small unit decision issues" (TRAC-WSMR –TR-04-009). Their Evaluation Report of March 2004 stated:

> Data is needed to represent the effects of different firing positions on engagement accuracy. A Soldier's accuracy is greatly affected by his firing posture and the weapons platform. A Soldier firing from a standing position is inherently less accurate than a Soldier firing from a more stable prone position. No model assessed accounts for the effects of different firing positions (standing, kneeling, prone, etc.). Numerous data voids exist for critical weapon/sensor parings. For example: PH for M4 with … the close combat optic in daylight.

These knowledge gaps guided the study's hypothesis and scope. This study also seeks to answer two specific questions regarding equipment and posture. First, does body armor affect a rifleman's probability of hit, and how does this affect the employment of the Squad Designated Marksman? Second, how effective are the Kneeling and Standing postures compared to the standard Foxhole and Prone postures. Are there potential benefits in conducting standardized training on these postures?

(a) Squad Designated Marksman

The Squad Designated Marksman (SDM) is a relatively new addition to the basic rifle squad and platoon. According to Army Field Manual 3-22.9:

> The primary mission of the SDM is to deploy as a member of the rifle squad. The SDM is a vital member of his individual squad and not a squad sniper. … The SDM has neither the equipment nor training to operate individually or in a small team to engage targets at extended ranges with precision fires. The secondary mission of the SDM is to engage key targets from 300 to 500 meters with effective, well-aimed fires using the standard weapon system and standard ammunition. He may or may not be equipped with an optic.

As stated, the SDM will not have the equipment to operate alone, but is expected to engage targets at 300 to 500 meters. If the SDM's effectiveness is critical to the success of his unit, is there equipment he should or should not carry?

(b) Alternate Firing Postures

Posture is another area this study seeks to quantify. The Army conducts basic rifle marksmanship training on only two firing postures, the Foxhole Supported and the Prone Unsupported firing postures. Alternate firing positions, such as Kneeling and unsupported Standing, are infrequently employed in standard Army doctrine, but are gaining popularity among Soldiers as they provide better mobility during an offensive operation, especially in urban terrain (see Appendix C). Kneeling and Standing postures use the body armor's protection better than the Prone posture because they keep the torso—and thus the Small Arms Protective Inserts (SAPI)—facing the enemy. They are also offer better mobility than the Prone. Advancing from position to position in the Prone is suitable for vegetated rural terrain, but it is less suitable when maneuvering through the rubble, broken glass, and concrete of urban terrain. How do the Probabilities of Hit for Kneeling and Standing postures compare to those of Prone and Foxhole?

2.   Modeling Concept

What type of model best predicts Probability of Hit: physics-based or a statistics-based model. An accurate physics-based model of rifleman engaging a target is extremely difficult. It requires movement measurements of every joint in a Soldier's body, calculation of how those movements affect rifle stability, and precise modeling of the bullet along its trajectory to the target. A physics-based model would also need to account for the wind and air resistance effects on the trajectory. Given the time and resources available, the combination of these tasks would be infeasible for this study.

On the other hand, a statistical model using observational data allows inclusion of the factors we can measure and leaves those we cannot to the effects of random error. With a large sample, one can construct a model that is both flexible to known factors yet stochastically accurate to unknown or undesired factors. The model would predict the probability of a shooter successfully hitting a target at a set distance. A parent simulation could use those probabilities to determine the outcome of rifle engagements.

The model offers the same prediction benefits that a weather forecaster provides. A forecaster cannot unerringly predict whether a viewer in a precise location will see precipitation in a particular day. The meteorological models can, however, provide a probability of precipitation. If an area receives rain on 20% of the days in a year and every day the forecaster predicts a 20% chance of rain, the model is accurate, but not precise. If the meteorologist predicts, based on weather conditions, that there is a 70% chance of rain, the viewers expect him to be correct 70% of the time. Conversely, if he predicts a 10% chance of rain, the audience expects not to see rain 90% of the time. The weather forecaster must be both accurate and precise.

A statistical model, although precise, cannot explain the specific reason a Soldier does or does not hit a target. A good rifleman can miss a target because of factors beyond his control, such as a large gust of wind. An untrained Soldier

may make an extremely difficult shot once in a large number of trials. Conversely, an extremely precise weapon system can miss if intentionally misaimed, while a very inaccurate system may occasionally hit its target by the canceling of random errors.

A model that accurately represents a rifleman's skill and behavior cannot and should not be used as a tool to optimize systems or operator training. The designed experiment does not look at differences in training techniques, leadership styles, or methods of instruction to improve rifleman proficiency. The data available is a sample taken under a limited set of conditions. It does not consider factors such as fear, hunger, sleep deprivation, and the effects of enemy returning fire at the shooter—all of which can affect a concentrated rifle shot. Furthermore, using the model to find an "optimal" equipment configuration to maximize Soldier capabilities would be erroneous. Marksmanship skills are always open to improvement. Even an "optimal" equipment configuration would not adequately represent the maximum capability of any individual in all conditions.

C.   BENEFITS

The model can, however, provide insights into how equipment, coupled with tactics and doctrine, may produce successful combat outcomes. This Probability of Hit (PH) model provides a parent simulation with accurate variation for individual-on-individual engagements in a larger scenario. Additionally, the model can assist with better depicting close quarters and urban combat scenarios. The room-to-room fight associated with urban combat puts the rifleman in a critical role, in which his marksmanship skills are among the few precise means of eliminating a threat. Accurately modeling the individual rifleman, which this model enhances, can then produce more accurate urban combat simulations.

The model can also assist in focusing instruction and training of marksmanship skills. The model, with its analysis of multiple factors and the

interaction of those factors, can provide insights into strengths and weaknesses of current training standards. Lower probabilities of hit for a specific weapon type or aiming device may lead to insights on where additional training or technical knowledge should focus. The model may help identify elements within an organization that need additional instruction to correct marksmanship weaknesses, for example M4 riflemen and targets beyond 200 meters.

D.   THESIS FLOW

The following chapter, Chapter II, describes the experimental design variables and how they are recorded and varied. Chapter III discusses the type and structure of the data and provides summary statistics on several of the key factors. Chapter IV covers the modeling structure and the resulting logistic regression model. The final chapter offers tactical insights from the analysis, discusses how the models can improve current combat operation modeling, explains how to improve the model, and outlines the follow-on research opportunities.

II.   EXPERIMENTAL DESIGN

This chapter

- Outlines the design parameters and variables used in the study's data collection.

- Organizes the variables into two categories, Controllable and Non-Controllable Factors. Controllable factors are those variables the study could manipulate, such as the shooter's equipment or posture. Non-controllable factors are those the observer cannot or chooses not to change between trials, such as wind speed and temperature.

- Describes the on-site and after action procedures conducted to prepare the data for analysis.

A.   EXERIMENT PURPOSE

1.   Methods of Collection

A statistical model needs quantifiable data, and the more data, the better. There are four general ways to collect realistic data on marksmanship.

a.   *Historical Data*

One method is to use historical data from previous or current military operations. The advantage to this approach is that it includes both offensive and defensive factors plus all the neutral environmental factors that affect both sides. The disadvantages to historical data are that data are rarely, if ever, collected in real time. The data typically rely on memory and corroborated recollection, both of which are subject to error.

b.   *Marksmanship Simulators*

A modern technique available for collecting data is to use a marksmanship simulator, such as the Engagement Skills Trainer 2000 (EST), a 10-meter indoor simulator, in which Soldiers shoot at a video screen using realistic weapon mock-ups (PEO Soldier, 2005). The advantage is that the EST provides accurate recording of rifle movement immediately prior to the firing of the bullet, such as that caused by a trigger squeeze or breathing technique. This type of feedback is currently unavailable through other means of instrumentation.

One disadvantage is that results are calculated through the computer's programming and may be subject to calibration error. Another disadvantage is that the soldier is in an indoor, controlled environment and is not subject to the same environmental factors, such as wind and extreme temperatures, that are realities in combat.

c.   Surveys and Subject Matter Experts

Another option is to use survey data from personnel with engineering, human factor, and military small arms experience regarding equipment, posture and marksmanship. This method offers the benefit of capturing intangible or immeasurable factors gained only through experience. A disadvantage is that this method may also introduce a huge variance in opinions and perspectives. An informal survey was conducted to gather the insights of combat veterans, and this information is available in Appendix C. The quantity and type of information provided is useful in determining Soldiers' perception of equipment interactions, but the responses are not sufficient to build the precise mathematical analysis needed.

d.   Range Experiments

A more accurate and expensive method for collecting data is to use the results from an automated rifle range. This technique offers all the realism of environmental effects, such as wind, temperature and visibility, while maintaining a great deal of control over the shooter-target scenario parameters. Fortunately, this is the method used by the US Army to qualify rifleman. One advantage is that the cost of collecting data is reduced because the Soldier time, equipment and ammunition are already part of the unit's training resource plan. Another advantage is that existing range procedures create the data for analysis. One person can easily gather and process that information for analysis. With the proper data processing, this technique creates a separate record for each bullet fired.

2. How Much Data are Enough?

A company-sized unit (approximately 129 Soldiers) can fire 5,000 to 30,000 rounds of ammunition in a single day of training. A mechanized brigade, such as the one that participated in this experiment, has over 15 companies and 2500 people. Each rifleman would qualify by firing at least 40 rounds—more if necessary—with an average of 100 rounds fired per person. The opportunity for collecting large amounts of data is readily available, and the remaining issue is deciding which factors provide the strongest information for the given problem. The following factors were chosen based on the availability of the information and its relevance to a potential Probability of Hit model.

B. CONTROLLABLE FACTORS

1. Soldier—Test Subjects

The Soldiers who conducted the experiments were from the 1st Brigade, 1st Infantry Division (Mechanized) of Fort Riley, Kansas. The experiment was conducted in conjunction with the unit's scheduled rifle training. The unit's training objectives were to conduct day Qualification Record Fire as outlined in US Army Field Manual 3-22.9. In addition to observing standard qualification of the brigade, one platoon from B Company, 1st Battalion, 16th Infantry Regiment (Mechanized), lead by 2LT Darryl Hill, was resourced to conduct additional marksmanship testing. These 29 Soldiers, after conducting required unit training, conducted additional non-standard firing tables as prescribed by the design of experiment.

The soldiers were not screened or selected for any specific type of training prior to their execution of the qualification tables. This study assumes that all participants had previously qualified with an M16 or M4 rifle prior to the day of testing. Rifle qualification is a graduation requirement for Basic Training and is also a Fort Riley requirement. The study does not look at the period of time that passed since the previous rifle qualification or the prior level of qualification (Marksman, Sharpshooter, or Expert).

2. Soldier Posture

The experiment covered four different firing postures. The two primary postures were the Foxhole Supported Position, shown in Figure 3, and the Prone Unsupported Position, shown in Figure 4. The two alternate positions were the Kneeling Position, shown in Figure 5, and the Standing Position, shown in Figure 6. All participants fired from the Foxhole and Prone positions as part of the unit training, but only the Test Platoon fired from the Kneeling and Standing Postures. Figures 1, 2 and 3 are photographs of the Soldiers while they were conducting the firing experiments.

In the Foxhole Supported Fighting Position, or Foxhole posture, the soldier stands inside a concrete structure with the top of the foxhole at mid-chest level. The Soldier has sand bags available to support his hands and stabilize the weapon. Soldiers may lean or rest any part of their body on the foxhole to create a stable firing position. If the foxhole is too deep for the firer, steps or blocks are available to improve his position, but the result may not be optimal for the soldier's height and equipment. The study therefore expects a relationship between soldier height, equipment, and firing accuracy from the Foxhole posture.

Figure 3.   Foxhole Supported Firing Position

In the Prone Unsupported Firing Position, or Prone, firers lie on their stomachs, as seen below. The Soldier does not have sandbags or other stabilization devices and must stabilize the weapon using only his hands and

arms.   Interceptor Body Armor (IBA) with Small Arm Protective Inserts (SAPI) can add two to four inches to the height of a soldier's prone position. This may cause a change in accuracy when wearing body armor in the Prone Position.

Figure 4.   Prone Unsupported Firing Position

The Kneeling Position, shown in Figure 5, is an alternate position not used during the standard qualification tables but used by the Test Platoon to test alternative firing postures. No requirements or restrictions were given to the test subjects while they used this position, other than requiring one foot to remain flat on the ground.

Figure 5.   Kneeling Firing Position

The Standing Position, shown in Figure 6, is another non-standard firing position. No restrictions were placed on the test subjects while they were using this posture, although unlike the figure below, current training guidance recommends that the shooter to stand with both feet square to the target, instead of off-set, as shown. The reason for this is that by keeping the feet square, the Soldier's shoulders—and hence the body armor he is wearing—remain forward, creating the most protective posture possible. The Soldiers used the Standing Posture in the short-range experiments only. For this reason, the effects of this posture may not be directly comparable to the other three postures.

Figure 6.   Standing Firing Position

3.   Soldier Equipment Configuration

The typical Soldier from the 1st Brigade, 1st Infantry Division (Mechanized) fires an M16A2 Rifle. Variations in this configuration include the M16A4 Rifle, the M4 Carbine, and the M16 or M4 Rifles with attached M203 Grenade Launcher, shown in Figures 7 through 9. About 15% of the subjects, mostly senior leaders, use the M68 Close Combat Optic, seen in Figure 10—while the rest of the Soldiers use the traditional ironsight. Standard survivability equipment includes

both a ballistic helmet, the Personal Armor System Ground Troops (PASGT) Kevlar helmet, seen in Figure 14, and ballistic body armor, the Interceptor Multi-Threat Body Armor System (IBA) with Small-Arms Protective Inserts (SAPI), seen in Figure 13. All ammunition in the study was M855 5.56-mm Ball.

Figure 7.   M16A4 Rifle with Standard Ironsights
(From: Colt, Inc.)

Figure 8.   M4 Carbine Modular Weapon System with M68 Close Combat Optic
(From PEO Soldier)

Figure 9.   M203 Grenade Launcher
(From PEO Soldier)

Figure 10.   M68 Close Combat Optic
(From PEO Soldier)

Figure 11.   Sight Picture of Iron Sight (From FM 3-22.9)

Note: Red Aimpoint does not change with parallax shift of sight picture
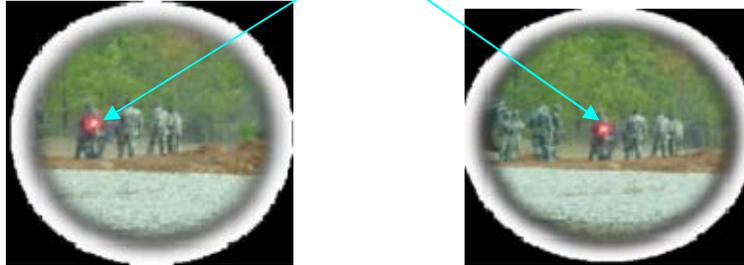
Figure 12.   Sight Picture of M68 CCO (After AIMSS)

Figure 13.   Interceptor Body Armor
(From PEO Soldier)

Figure 15.   Interceptor Body Armor with
PASGT Helmet (From RDECOM)

Figure 14.   Personal Armor System for
Ground Troops (PASGT) Helmet
(From FAS.org)

Figure 16.   Advance Combat Helmet
(From PEO Soldier)

C. NON-CONTROLLABLE FACTORS

1. Range Design

The short-range observations are from an Army Modified Record Fire Range. This type of standardized range offered a fully automated target scenario controlled and evaluated from the range operations center. Targets were situated at 50, 75, 100, 150, 175, 200, 250, and 300 meters. The range used two types of targets. At the 50, 75, and 100-meter range, the targets were 26" high F-type targets, shown in Figure 17, representing the head and shoulders of a human. From 150 to 300 meters, the targets were 40" high E-type "Ivan" Targets, shown in Figure 18, representing a standing human.

Figure 17.   F-Type Silhouette

Figure 18.   E-Type Silhouette, Front and Side View

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The short-range observations were conducted on an Automated Combat Pistol Range. These ranges have E-type targets, such as Figure 18, with baseline ranges at 10, 13, 16, 17, 23, 27, and 31 meters. Pistol ranges do not have fighting positions (foxholes), but all other firing postures are possible. On a pistol range, a standing rifleman is generally at the same level as the targets, with the "head" of the target standing at about 4.5 feet above the ground.

The study assumes there is no error in the target system. The Range Control personnel were very diligent in maintaining their facilities. While Soldiers notoriously accuse the target equipment of "robbing" a legitimate hit (thus denying them of a higher qualification), the range computer had internal diagnostics to determine such failures. The target alerted the range operator of suspected targets, and those with problems were either repaired or isolated (i.e., the lane was no longer used for qualification).

2. Target Angle

The qualification range used two different sized targets, and the model needed a common scale to measure the relative size of the one target to another. One solution to overcome this is to relate both targets and their ranges as a target angle. A smaller target angle means there is less tolerance for any deviation for aiming or ballistic error. For example, an apple on a fencepost at 100 meters is more difficult to hit than the side of a barn at 150 meters because the target angle—the angle from the bottom to the top of the target—is smaller. In a similar manner, a head and shoulder silhouette target at 100 meters may be more difficult than hitting a full-body silhouette target at 150 meter, as shown in Figure 19.

Smaller Target Angle = Less Tolerance for Error = More Difficult Shot

100 meters
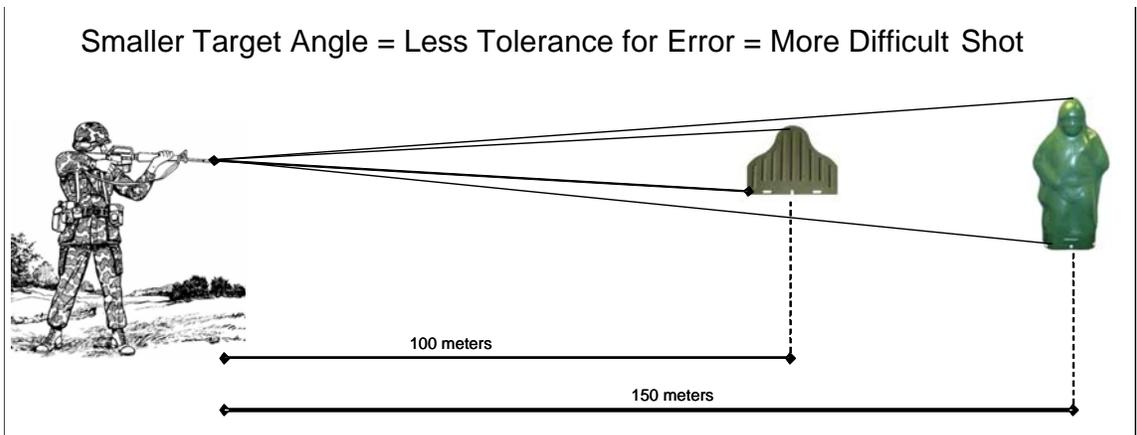
150 meters

Figure 19.   Target Angle

A common unit for a target angle is Mils. 17.8 mils = 1 degree, and this angle corresponds to the width or height of 1 meter at 1000 meters distance. The targets are roughly the same width, 20" to 21" for E and F type targets, respectively. This makes it possible to create, on a continuous scale, the angle created by the target at a given distance. For example, the target angle for an E-type target that is 40" tall at 150 meters would be calculated as follows:

$$\frac{40\,inches \cdot 0.0254\,\dfrac{meter}{inches}}{150\,meters \cdot \dfrac{1\,mil \cdot 1\,meter}{1000\,meters}} = 6.77\,mil.$$

Equation 1:   Mils Calculation Example

In this way, the 40" E-type targets at 150 meters with a 6.77 mils target angle is actually easier to hit than the 26" F-type target at 100 meters with a 6.60 mils target angle. While this measurement is only an approximation—a precise measurement that requires target surface area and not just height—it is an accurate estimate of the difficulty of each shot. Because the target angle uses target range as an input variable, the two factors are highly correlated. Placing both factors in a model could confound the effects of other variables.

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3. Target Exposure Time

Changing the target exposure time was possible, but the time required was disruptive to the unit's primary training. The target exposure times were therefore as prescribed in US Army Field Manual (FM) 3-22.9 for the Rifle Ranges and FM 3.22-14 for the Pistol ranges. The target exposure time generally increases as the target range increases, with additional time allotted for multiple (two) target scenarios. This was to allow for the additional acquisition and engagement time for long-range and multiple targets.

4. Soldier Anthropometrics

The Soldiers who conducted the testing were not screened for anthropometric characteristics. Soldier height and weight were only collected on the Test Platoon Soldiers. The average Soldier from the Test Platoon was 70.0 inches and 181 pounds.

5. Soldier Experience

The soldiers were not screened for any type of training or level of experience. The average experience in terms of years of service was 4.42 years. Although the Soldiers' combat experience was not surveyed, roughly half the Soldiers had recently returned from Operation Iraqi Freedom.

6. Soldier Military Occupational Specialty (MOS)

A majority of the Soldiers were either Infantrymen, Field Artillerymen, or Bradley Linebacker Crewmembers. All members of the Test Platoon were Infantrymen. In addition to the Combat Soldiers of the brigade, there was a wide array of Combat Support and Combat Service Support MOSs in the headquarters units as well. The observations were a fair sample of an Army maneuver brigade's distribution of MOSs.

Because of the high number of MOSs, some with only one or two individuals, the MOSs were aggregated into two groups: Combat or Support.

The intent was to determine if Combat MOSs, with their focus on offensive combat tasks, had a higher Probability of Hit than their Support MOS comrades.

7. Weather

The weather during the experiment was generally cold and dry. The average ambient temperature was 41.9° Fahrenheit. The range facilities did not have immediate meteorological data available, so the study uses National Weather Service (NWS) data from the nearest weather station, the Manhattan Regional Airport, approximately 10 miles east of the range location. The weather information is used to determine two effects: the effect of wind deflection on the bullet, and the effect of temperature and wind on soldier stability (i.e. shaking from the cold).

The National Weather Service provided hourly information. The wind measurements, therefore, are not exact for each observation. The effects of the wind are approximated as such:

$$\text{lateral wind deflection } \textit{(meters)} = \frac{\text{sine}\left(\text{angle of wind} - \text{angle of range}\right) \cdot \text{wind speed} \cdot \text{target range}}{\text{bullet muzzle speed}}.$$

Equation 2: Estimation of Lateral Wind Deflection

In addition to wind deflection, the direct effects of a shooter's body shaking due to weather were not measurable, but must be assumed to exist. The Soldiers were generally exposed to the elements for most of the day, and their exposure to the meteorological elements was not controlled or recorded. The use of cold weather equipment such as gloves, thermal underwear, and knit caps were not recorded. The study expected to see that wind had a negative effect and temperature had a positive effect on Probability of Hit. In other words, warm and calm weather would be better than cold and windy weather.

8. Weight of Equipment

The study recorded the Soldier's total weight with equipment prior to firing each table. Knowing the total equipment weight provided an estimate of the effects of this weight on marksmanship. The study measured total weight for most firers, but received naked weight for only the Test Platoon. The estimated equipment weight for these soldiers was significant. Soldiers from the Test Platoon were carrying an average of 57.2 pounds while firing. This weight is still below combat equipment weight and does not include the 210+ rounds of ammunition, two to four grenades, and additional gear a fully combat-loaded Soldier carries.

D. TESTING SEQUENCE

There were a total of 10 different firing tables in the experiment. The first two tables were the standard Qualification Record Fire, and the remaining eight tables were alternate tables for experiment purposes. All soldiers fired Tables 1 and 2 wearing IBA in accordance with the brigade's training policy. Only the Test Platoon Soldiers conducted Tables 3 through 10. The sequence of posture and equipment treatments by firing table is in Table 1.

Table 1.   Range Experimental Tables

Table	Engagement	Posture	Equipment	Participants
1	1-20	Foxhole Supported	Standard with IBA	All
2	21-41	Prone Unsupported	Standard with IBA	All
3	41-60	Kneeling	Standard with CCO (if issued)	Test Platoon
4	61-80	Prone Unsupported	Standard, CCO, w/o IBA	Test Platoon
5	101-120	Foxhole Supported	Standard Night Equipment	Test Platoon
6	121-140	Prone Unsupported	Standard Night Equipment	Test Platoon
7	141-160	Kneeling	Standard Night Equipment	Test Platoon
8	161-180	Prone Unsupported	Standard Night Equipment w/o IBA	Test Platoon
9	213-242	Standing	Standard*	Test Platoon
10	213-242	Standing	Standard w/o Body Armor*	Test Platoon

Soldiers shot Tables 1 and 2 wearing IBA until they qualified, hitting 23 or more targets out of 40. After qualifying, the Test Platoon shot Tables 3 and 4, using the same target scenarios but changing posture and equipment. Using the same target scenario of Tables 1 and 2 allowed the Test Platoon experiments to be interspersed with the standard qualification firers. Table 3 was identical to Table 1, except that the Soldiers shot from the Kneeling posture instead of the Foxhole. Table 4 had the same posture as Table 2, but the Soldiers did not wear body armor. In this way, comparing the Foxhole with Kneeling postures and body armor with no Body Armor is possible. Additionally, several, but not all, Soldiers changed aiming devices from Ironsight to M68 Close Combat Optics for Tables 3 and 4. This allows for a comparison of both aiming devices

The Test Platoon fired the standard Night Qualification Record Fire as prescribed in FM 3-22.9 for Tables 5 and 6. This provided a close comparison of daytime to nighttime conditions. The Soldiers then repeated the scenarios as

Tables 7 and 8, with the same alterations as daytime. Table 7 was identical to Table 5 except that the Soldier used the Kneeling posture instead of the Foxhole. Table 8 matched Table 6, except that the Soldier removed his body armor. The combinations of Tables 1 through 8 thus provide cross comparisons of posture, equipment, and visibility conditions.

Tables 9 and 10 were short-range tables. They were identical in target presentation except that Soldiers wore IBA in Table 9 and did not in Table 10. The Soldiers also shot these tables in different sequences. Half of the group shot Table 9 and then Table 10. The second half shot Table 10 and then Table 9. This was to reduce the learning effect of shooting a non-standard table.

E. DATA COLLECTION

1. Prior to Shooting

During normal range operations, a designated person records the name and an identification number for each rifleman, along with his or her corresponding firing lane. This allows the ranger personnel and the study to link scores with the owners. The study modified this standard procedure to also record the Soldiers' type of equipment: weapon, helmet, body armor, aiming device, infrared aiming device, and night vision goggle (if firing at night).

The study gathered personal data—Soldier MOS, Time in Service, and unit information—from the battalion Personal Action Centers. The Soldier identification number links the results from the range with the personal information.

2. After-Testing Procedures

Once the firing table was complete, the range manager provided a copy of the firing order manifest and a record of the firers in both digital and paper form, as seen in Figure 20.

The range results became part of a relational database that recorded each bullet as a separate record and links these results to the Soldier data collected prior to firing. The final data for each record contains:

- Binary Engagement Results (Hit or Miss)
- Soldier's Personal Information (MOS, Rank, Time in Service)
- Equipment Used While Firing (Rifle, Aiming Device, Body Armor)
- Table Specifications (Target Range and Exposure, Soldier Posture)
- Time and Environmental Conditions

F.   DATA LIMITATIONS

1.   Hit Location or Miss Proximity

The range computer records a binomial outcome: Did the target sensors detect the strike of the round? It did not provide the location of a successful hit, nor did it provide the miss distance. This limitation restricts the analysis to predicting the Probability of Hit instead of the location of hit for each round.

There is a modern addition to the hit detection sensor called the Location of Miss and Hit (LOMAH). It uses a radar array at the target's base to measure the location of the bullets trajectory as it break the plane of the target. LOMAH gives a radial miss distance rather than a binomial response. The benefits of this are discussed in Chapter V.

```
Unit: 1ST BDE    Firing Order:  7    RECFIRE.pgm    Wednesday December 3, 2004

         --------------------------------------------------
SEQ DIST    1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16
--- ----   -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
  1   50             1  1     1  1  1  1  1     1  1
  2  200             1  1     1             1     1
  3  100             1  1     1  1     1        1  1
  4  150             1  1  1  1  1     1        1  1
  5  300             1  1        1     1
  6  250                      1  1     1           1
  7   50             1  1  1  1  1  1  1     1  1  1
  8  200                      1  1
  9  150             1  1     1  1  1           1
 10  250                         1  1     1     1  1
 11  100                      1  1  1     1     1  1
 12  200                         1                 1
 13  150             1  1  1  1  1  1  1           1
 14  300                         1  1
 15  100                1        1  1  1  1     1  1
 16  250                         1  1  1
 17  200                1        1  1  1        1  1
 18  150             1     1  1  1  1           1  1
 19   50             1  1  1     1  1  1     1  1  1
 20  100             1        1  1  1  1        1  1
 21  100             1  1     1     1  1  1     1  1
 22  250             1           1                 1
 23  150             1  1     1  1  1  1  1  1     1
 24   50             1     1  1  1  1  1  1  1     1
 25  200             1  1     1  1  1
 26  150             1  1  1  1  1  1  1  1  1  1  1
 27  200             1  1     1     1           1  1
 28   50             1  1  1     1  1  1  1  1  1  1
 29  150             1  1  1     1  1  1  1  1  1
 30  100             1  1  1     1     1     1  1  1
 31  150             1  1     1  1  1  1        1
 32  300             1  1                    1     1
 33  100             1  1     1  1  1  1     1  1
 34  200             1  1  1  1  1  1           1  1
 35  150             1  1  1  1  1     1     1  1  1
 36  250                1           1           1  1
 37  100             1  1  1  1  1  1  1     1  1  1
 38  150             1  1     1  1  1  1     1  1  1
 39  100             1  1     1  1  1  1           1
 40  200             1  1     1  1                 1
         -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
TOTALS              29 29 14 27 34 28 26 11 17 23 32

LANE SCORE  QUALIFICATION    ID          NAME
---- -----  -------------    --          ----
  1
  2
  3
  4   29    MARKSMAN          9538        TOSCO, 1/16
  5   29    MARKSMAN          7191        JOHNSONS, 1/16
  6   14    UNQUALIFIED       7090        SRUNT, 4/3
  7   27    MARKSMAN          8724        KURIDDIN, 4/3
  8   34    SHARPSHOOTER      7370        VALETTE, 4/3
  9   28    MARKSMAN          2170        STAMPO, 1/16
 10   26    MARKSMAN          4650        PARERO, 1/16
 11   11    UNQUALIFIED       6375        HENDERSON, 1/16
 12   17    UNQUALIFIED       7547        STAIL, 1/16
 13   23    MARKSMAN          3507        DAVIS, 4/3
 14   32    SHARPSHOOTER      2549        TURNEY, 1/16
```

Lane 14, T2549

Figure 20.   Range Computer Output File

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2. Short Range Postures—Standing Only

The opportunity to use the Combat Pistol Qualification Course, Range 2 at Fort Riley came only after a great deal of hasty coordination and convincing. The Range Control personnel, therefore, granted the request under very stringent controls. No prone position firing was conducted on account of the range limitations. As a result, the data from Range 2 on 12 December 2004 were not as robust in terms of posture, equipment, and observations as were the experiments on the standard qualification ranges.

More importantly, all firing for short ranges is from the Standing posture. Thus, the estimates of Probability of Hit for short range data may not be directly comparable to the long-range data.

G. SUMMARY

Each observation collected is a virtual snapshot of the shooter, target and environment at the moment of firing. The data uses many tangible items as factors—type of weapon, aiming device, posture, etc. The type of equipment was simple to identify, but the effects of that equipment are more difficult to estimate. Does the equipment cause the effect, or was the Soldier just more confident when using it? The following chapter profiles several of the tangible factors. For each variable, the summary statistics discuss the distribution, differences, and significance of those differences.

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III.   STATISTICAL SUMMARY

This chapter

- Contains a baseline statistical analysis of the data.

- Presents baseline statistics on the data and significance of the differences.

- Discusses shortcomings in the current model and presents possibilities for follow-on research.

A.   DATA STUCTURE

The collected data represents observational information on each of 29,005 shots by 466 Soldiers. The data variables can be grouped into three categories: Shooter, Target, and Environmental Variables. The response variable is the binary outcome of hitting or missing the Target.   The list of variables is below in Table 2. The highlighted fields, marked in yellow and with *, are information available only on the Test Platoon Soldiers. This anthropometric information— height, weight and physical fitness ability—were recorded during a diagnostic Army Physical Fitness Test conducted on the last day of firing.   All other information was recorded prior to or during the experiment.

Table 2.   List of Observation Variables

SHOOTER VARIABLES	Variable Type	Example
SOLDER ID	Unique ID given to each test subject	K1234
SOLDIER RANK–PAY GRADE	Rank Soldier	Specialist, E-4
MILITARY OCCUPATIONAL SPECIALTY (MOS)	Primary occupation of test subject	11B, Infantryman
EXPERIENCE/YEARS OF SERVICE	Years of service of test subject, measured from his Basic Active Service Date (BASD)	1.234 years
TOTAL EQUIPMENT LOAD*	Weight of test subject while holding all equipment and ammunition	110 kilograms
SOLDIER HEIGHT*	Height of Soldier without footgear or headgear	1.85 meters
SOLDIER WEIGHT*	Naked weight of Soldier	85 kilograms
SOLDIER PHYSICAL FITNESS ABILITY*	Army Physical Fitness Test score - 300 max.	256 points
SOLDIER POSTURE	Shooting posture	Kneeling
SOLDIER UNIT	Platoon / Company / Battalion	3/B/1-16 IN
SOLDIER UNIT TYPE	Type of battalion	Field Artillery
WEAPON TYPE	DOD nomenclature of rifle	M4 MWS Carbine
WEAPON SIGHT TYPE	DOD nomenclature of weapon sight	M68 CCO
BODY ARMOR TYPE	Nomenclature of body armor	IBA
HELMET TYPE	Nomenclature of helmet model	PASGT
NIGHT VISION TYPE	Nomenclature of night vision device	A/N-PVS 14
NIGHT AIMING DEVICE TYPE	Nomenclature of infrared aiming device	A/N-PEQ 2A
TARGET VARIABLES	Variable Type	Example
TARGET DISTANCE/RANGE	Distance from shooter to target	250 meters
TARGET ANGLE	Angle of target silhouette from shooter	6.76 mils
TARGET TYPE	Type of target silhouette	E-type - 1
TARGET TIME OF EXPOSURE	Time of target exposure to shooter	5 seconds
SINGLE OR MULTIPLE TARGETS	Single-1 target or Multiple- 2 targets	Multiple
ENVIRONMENTAL VARIABLES	Variable Type	Example
FACILITY LOCATION	Name of firing range	Range 2
SHOOTER'S LANE NUMBER	Firing lane of shooter	Lane 11
TIME OF OBSERVATION	Time of day of observation	1430 CST
DATE OF OBSERVATION	Day of shooting	10 DEC 04
AMBIENT TEMPERATURE	Temperature of air temperature	-1° C
BAROMETRIC PRESSURE	Pressure in inches mercury	30.12 inches
WIND SPEED	Average wind speed	5 meters per second
WIND DIRECTION	Compass direction of wind	295° Magnetic
CLOUD COVER AND LEVEL	Fraction of sky covered by clouds	3/8

*Highlighted Fields are for Test Platoon Only

B. PRELIMINARY FINDINGS

1. Correlation of Numeric Variables and Response Variable

Table 3 shows variable correlations for the entire population of Soldiers. As expected, the target range is highly correlated with mils, time exposure, and wind deflection, with ρ equaling -0.859, 0.353, and 0.597, respectively. As the target range increases, the target angle decreases, the time exposure increases (by design), and the expected wind deflection increases. This means that targets looks smaller, exposure time increases, and wind effects increase when the target is farther away. Not expected in this table is the correlation between wind speed and time of day. In Fort Riley, as in most places, the morning wind is not as strong as the wind in the afternoon.

Table 3.　　Correlation of Numeric Variables for Entire Sample

Correlations										
	HIT_MISS	WEIGHT	YEARS_OF_SERVICE	MILS	TIME_EXP	TGT_RANGE	TIME	WIND_DFLX	SPD	TEMP
HIT_MISS	1.0000	0.0400	-0.0009	0.2994	-0.0736	-0.3666	-0.0450	-0.2030	0.0066	-0.0389
WEIGHT	0.0400	1.0000	0.1772	-0.0006	-0.0105	0.0024	-0.0550	-0.0504	-0.0638	-0.0303
YEARS_OF_SERVICE	-0.0009	0.1772	1.0000	-0.0003	-0.0000	0.0003	-0.0651	0.0242	0.0431	0.0010
MILS	0.2994	-0.0006	-0.0003	1.0000	-0.3896	-0.8589	-0.0005	-0.5113	0.0003	0.0004
TIME_EXP	-0.0736	-0.0105	-0.0000	-0.3896	1.0000	0.3527	0.0003	0.2102	-0.0011	-0.0006
TGT_RANGE	-0.3666	0.0024	0.0003	-0.8589	0.3527	1.0000	-0.0020	0.5966	0.0015	-0.0006
TIME	-0.0450	-0.0550	-0.0651	-0.0005	0.0003	-0.0020	1.0000	-0.0706	-0.1601	0.2298
WIND_DFLX	-0.2030	-0.0504	0.0242	-0.5113	0.2102	0.5966	-0.0706	1.0000	0.6591	0.2093
SPD	0.0066	-0.0638	0.0431	0.0003	-0.0011	0.0015	-0.1601	0.6591	1.0000	0.5347
TEMP	-0.0389	-0.0303	0.0010	0.0004	-0.0006	-0.0006	0.2298	0.2093	0.5347	1.0000

4104 rows not used due to missing values.

Especially interesting is the correlation of HIT_MISS with the other variables.   HIT_MISS is the binary response variable.   Among the other variables, those associated with target distance—target range, target angle (MILS), and wind deflection—have the most influence. Because target angle and wind deflection are both functions of target range, their strong correlation was expected.

The correlation of variables for the Test Platoon in Table 4 shows some interesting differences from the general population.   The columns within the dashed border are unique to the Test Platoon.   As expected, a strong

relationship exists between Soldier Height and Soldier Weight ($\rho = 0.584$) and Soldier equipment and Soldier Equipment Weight Ratio ($\rho = 0.914$). Taller Soldiers tend to weigh more and carry more equipment than shorter Soldiers. One correlation is particularly interesting: the relationship between ambient temperature (TEMP) and Soldier Equipment Weight. The correlation ($\rho = -0.278$) suggests that as temperature decreases, Soldiers are wearing more equipment. Soldiers, as with most people, wear additional clothing when it is cold. Another difference between the Test Platoon and the whole population is that for the Test Platoon, Years of Service has a stronger correlation with HIT_MISS. The correlation between the two groups, $\rho = 0.111$ for the Test Platoon versus $\rho = -0.0009$ for the entire sample, suggests that experience matters for the infantrymen, but it is not an influential factor for the average soldier.

Table 4.   Correlation of Numeric Variables for Test Platoon

Correlations

	HIT_MISS	SOL.HT.M	WT	Equip. Weight	EQUIP_RATIO	APFT	YRS_OF_SRVC	MILS	TIME_EXP	RANGE	TIME	WIND_DFLX	SPD	TEMP
HIT_MISS	1.0000	0.1170	0.0238	0.0285	0.0088	-0.0801	0.1521	0.2544	-0.0937	-0.3137	-0.1163	-0.1858	0.0328	-0.0537
SOL.HT.M	0.1170	1.0000	0.5838	0.0055	-0.2673	-0.3791	-0.0149	0.0008	-0.0003	-0.0011	-0.0114	-0.0927	-0.0837	-0.0161
WT.KG	0.0238	0.5838	1.0000	0.5876	0.2298	-0.3579	0.2626	-0.0030	-0.0853	0.0201	-0.1938	0.0079	0.0028	-0.0902
Equipment Weight	0.0285	0.0055	0.5876	1.0000	0.9138	-0.0231	0.3098	-0.0060	-0.1644	0.0393	-0.3970	0.0472	0.0657	-0.2780
EQUIP_WT_RATIO	0.0088	-0.2673	0.2298	0.9138	1.0000	0.1522	0.1912	-0.0058	-0.1536	0.0370	-0.3828	0.0624	0.0869	-0.3163
APFT	-0.0801	-0.3791	-0.3579	-0.0231	0.1522	1.0000	-0.3294	-0.0017	0.0007	0.0023	0.1289	0.0983	0.0941	0.0386
YEARS_OF_SERVICE	0.1521	-0.0149	0.2626	0.3098	0.1912	-0.3294	1.0000	-0.0010	0.0004	0.0014	-0.3293	-0.1010	-0.0141	0.1173
MILS	0.2544	0.0008	-0.0030	-0.0060	-0.0058	-0.0017	-0.0010	1.0000	-0.3751	-0.8581	0.0054	-0.5415	-0.0058	0.0083
TIME_EXP	-0.0937	-0.0003	-0.0853	-0.1644	-0.1536	0.0007	0.0004	-0.3751	1.0000	0.3287	-0.0023	0.2153	0.0025	-0.0036
TGT_RANGE	-0.3137	-0.0011	0.0201	0.0393	0.0370	0.0023	0.0014	-0.8581	0.3287	1.0000	-0.0075	0.6311	0.0080	-0.0115
TIME	-0.1163	-0.0114	-0.1938	-0.3970	-0.3828	0.1289	-0.3293	0.0054	-0.0023	-0.0075	1.0000	-0.1802	-0.2693	0.7005
WIND_DFLX	-0.1858	-0.0927	0.0079	0.0472	0.0624	0.0983	-0.1010	-0.5415	0.2153	0.6311	-0.1802	1.0000	0.6577	-0.3316
SPD	0.0328	-0.0837	0.0028	0.0657	0.0869	0.0941	-0.0141	-0.0058	0.0025	0.0080	-0.2693	0.6577	1.0000	-0.4161
TEMP_C	-0.0537	-0.0161	-0.0902	-0.2780	-0.3163	0.0386	0.1173	0.0083	-0.0036	-0.0115	0.7005	-0.3316	-0.4161	1.0000

1830 rows not used due to missing values.

2.   Average Probability of Hit by Target Range

Are the observed Soldiers representative of the population of Soldiers in the Army? The Army has an expected Probability of Hit for rifle qualification tables such as the ones observed. The Army's rifle Qualification manual, Field Manual 3-22.9, states that trained riflemen should shoot within the range of probabilities seen in Table 5 and graphed in Figure 21. The Low, Average, and High Probability of Hits in Table 5 corresponded to the expected proportions of hits for a Marksman (23 hits out of 40), Sharpshooter (32 / 40) and Expert (36/40) rifle qualifications. These are intended as guides for unit leaders to gauge their

training programs against published Army standards.   These probabilities are realistic and are good standards for training proficiency.   They may not be realistic for modeling combat situations.   The upper limit of these probabilities seems extremely optimistic, especially considering that in Vietnam 2,200 rounds of ammunition were required per enemy kill (Blahnik, 2005).

Table 5.   Expected Probability of Hit (From FM 3-22.9, 2004))

RANGE (meters)	TARGETS	LOW PH	AVERAGE PH	HIGH PH
50	5	0.80	0.95	0.98
100	9	0.70	0.90	0.95
150	10	0.65	0.90	0.95
200	8	0.45	0.70	0.90
250	5	0.35	0.60	0.85
300	3	0.25	0.50	0.80
TOTAL	**40**	**23 HITS**	**32 HITS**	**37 HITS**
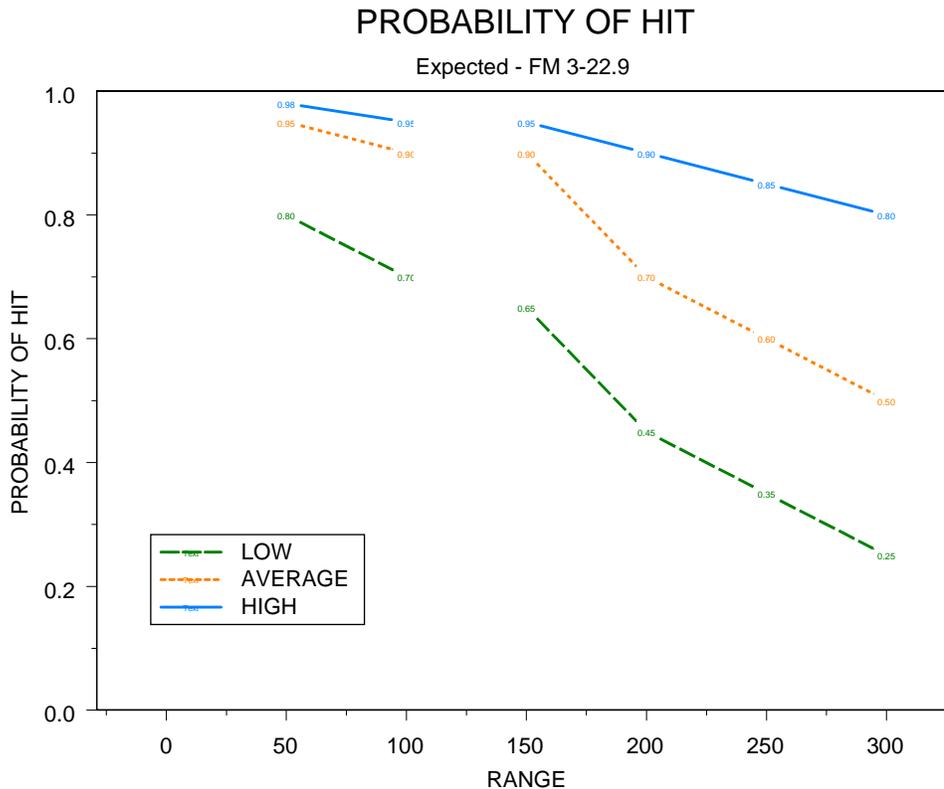
Figure 21.   Doctrinal Expected Probability of Hit

In Figure 22, the proportion of actual hits from the range experiments are plotted with the doctrinal Probabilities of Hit. The results from the range are very similar to the Low PH from Table 5. A Chi-Square Test (Appendix D) rejects the hypothesis that the observed Probabilities of Hit are equal to the doctrinal PH a *p*-value << 0.01. Even though the proportions look similar, the large number of observations causes any deviance from the expected PH very unlikely, and the Chi-Square Test to fail.

PROBABILITY OF HIT
Actual vs Expected
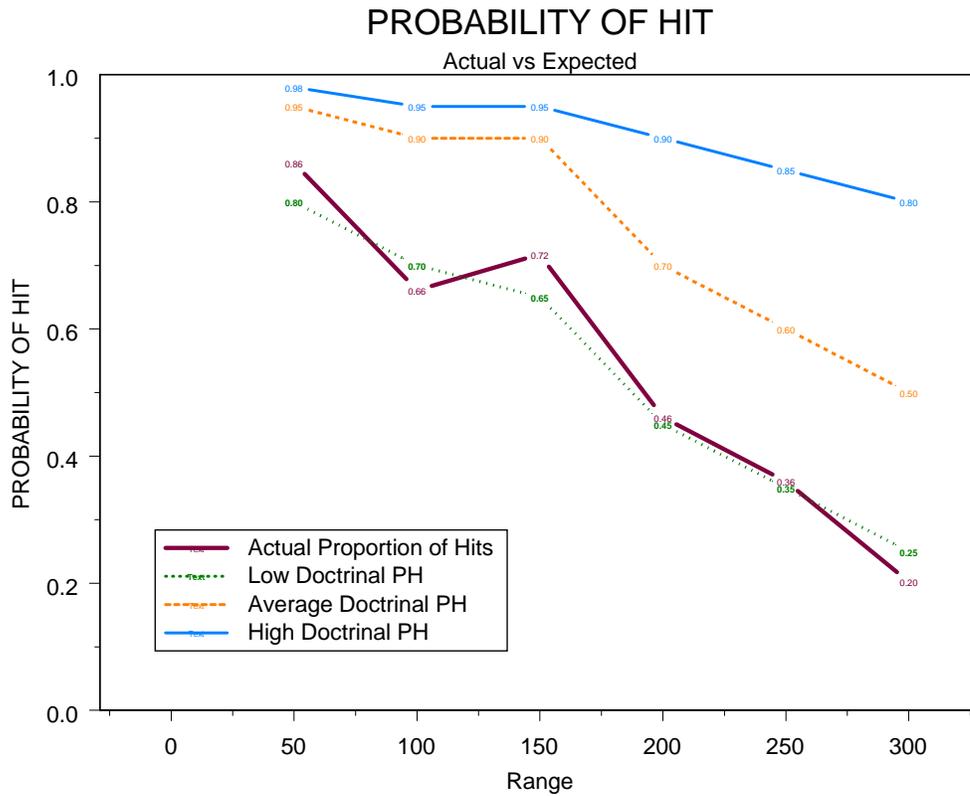
Figure 22.   Expected versus Actual Probability of Hit

The test becomes more interesting when the dataset is separated into those iterations resulting in a qualification and those that do not. As Figure 23 shows, the actual proportion of hits now lies between the doctrinal Low and Average PH. The Chi-Square again rejects the hypothesis that the qualified runs

are like any of the doctrinal Probability of Hits. This means that the qualified runs are better than the Low PH, but not quite as high as the Average PH.
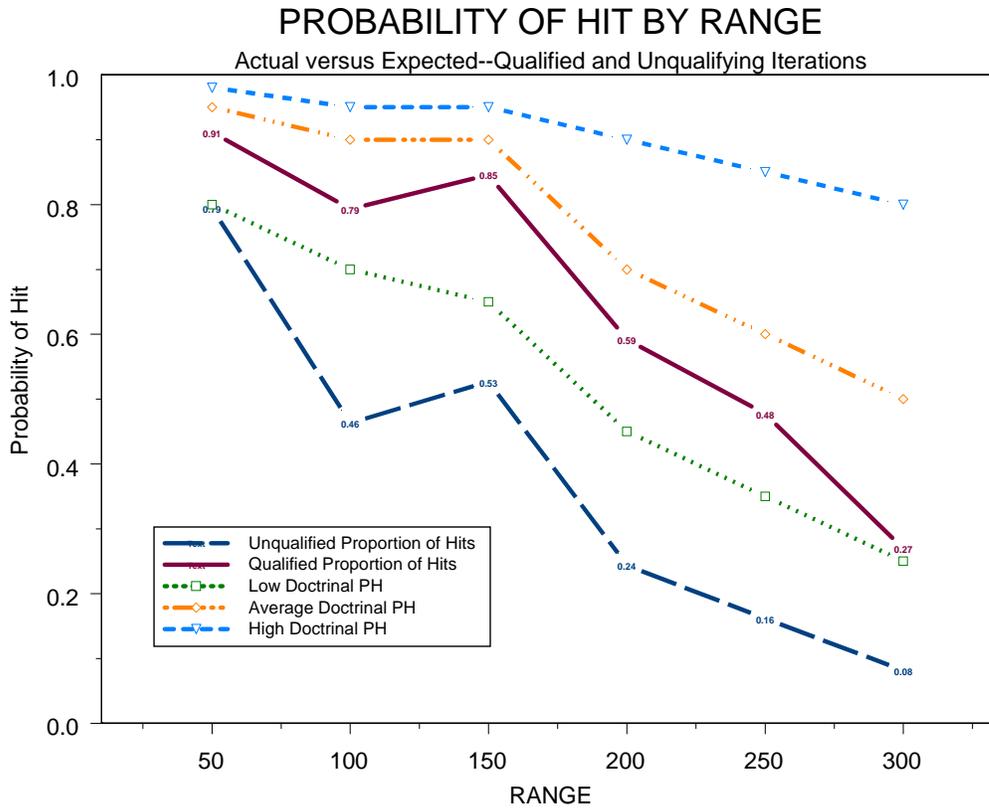
Figure 23.   Expected versus Actual Probability of Hit

Figure 24 and Figure 25 break the range observations into two groups, Short Range and Standard Range. This is due to the dramatic difference in Probability of Hit for Standing posture, which is conducted on the Short Range only. Figure 25 also shows the results of the Test Platoon against the Sample Population. The Chi-Square Test fails to reject the hypothesis that the Test Platoon is similar to the Sample Population with p-value = 0.2091. The same test rejects the hypothesis that either population is similar to any of the doctrinal Probabilities of Hit. This means that the data from the Test Platoon reasonably reflects the Sample Population. The Test Platoon, even though they are all Infantry rifleman, represents a good sample of observations from the entire

brigade. A model created with the platoon's data can reasonably predict the Probability of Hit for not only the platoon but also the brigade. Since the platoon was statistically similar to the expected doctrinal performance, the model from the platoon's data may reasonably predict the performance of the average US Army rifleman.

PROBABILITY OF HIT BY RANGE
SHORT RANGE
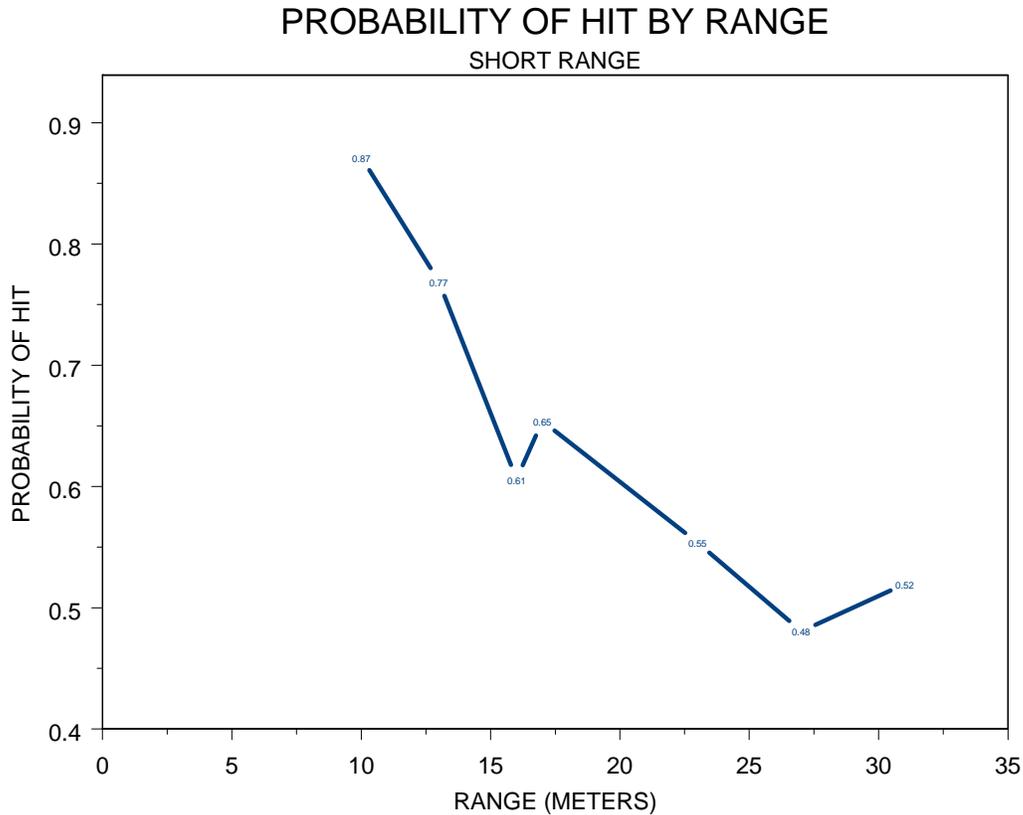
Figure 24.   Probability of Hit—Short Range

The Probability of Hit for both types of firing—standard and short range—decreases with target distance. The decrease, however, is much more rapid for the short range. The reason is that the short range data represent only the Standing posture, which is also the least stable posture, whereas the standard ranges are a composite of Prone, Foxhole, and Kneeling postures. This is discussed further in a subsequent paragraph. Also interesting is the increase in PH from 100 to 150 meters. As discussed in the topic of target angle, this is the effect of the E-type target at 150 meters having a larger target angle—a larger

relative size to the firer. This made the target "bigger" and easier to hit than the smaller F-type silhouette at 100 meters.

PROBABILITY OF HIT BY RANGE
TEST PLATOON VS. WHOLE SAMPLE
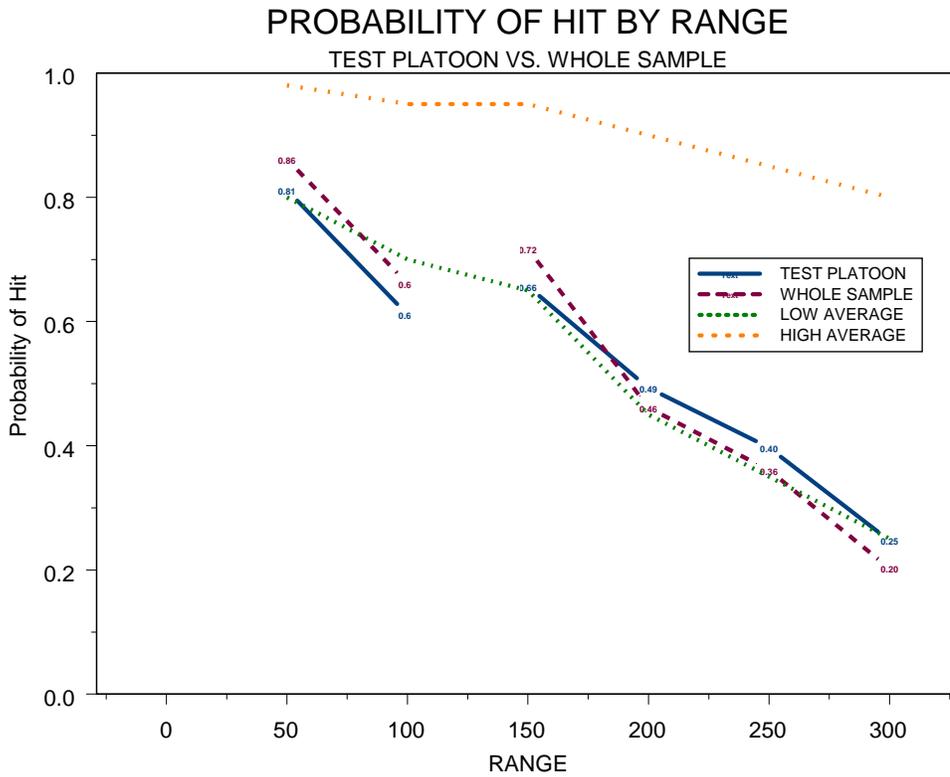
Figure 25.   Test Platoon versus Sample Population—Standard Range

3.   Probability of Hit by Body Armor

The initial hypothesis was that IBA body armor restricts natural movement and hence reduces the Probability of Hit for the Soldiers wearing it. As seen in Figure 26, for target ranges from 50 to 150 meters, those Soldiers wearing IBA actually shot better than those without IBA. This advantage, however, diminished as distance increased. At 200 meters, riflemen not wearing IBA shot better than those who were wearing it. The Chi-Square test rejects the null hypothesis that the two types of body armor were equal with a *p*-value << 0.01.

PROBABILITY OF HIT BY RANGE

By Body Armor - Day Prone Tables Only
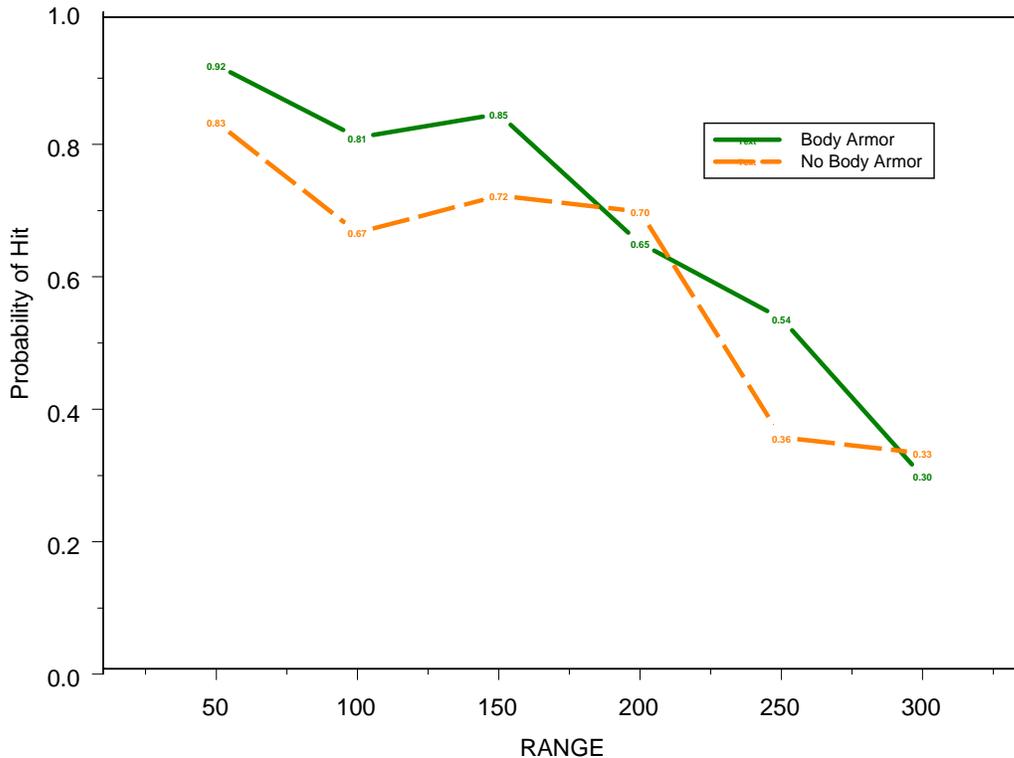
Figure 26.   Probability of Hit by Body Armor Type

A mitigating factor may explain the better performance with the IBA. The Soldiers conducted pre-marksmanship instruction (PMI) and zeroed their weapons while wearing body armor.   Therefore, they were trained and accustomed to shooting in IBA. This created a possible bias toward the IBA, and thus, shooting without body armor could introduce an additional error because the Soldier was unaccustomed with this equipment configuration.   The current data cannot prove this theory because no data were collected on the methods or equipment used prior to the experiment.

Table 6.   Distribution of Observations by Body Armor Type

Level	Count	Percentage
FLAKVEST	380	1.31%
IBA	27333	94.23%
NONE	1292	4.45%

That the non-IBA wearing Soldiers shot slightly better at longer ranges is a critical fact. As discussed in the Chapter I, the Squad Designated Marksman's primary engagement criteria are targets between 300 and 500 meters. The data suggest that the SDM might be more lethal without full body armor. Not wearing IBA might improve the SDM's marksmanship, but it also reduces his survivability against enemy fire. Ranges beyond 300 meters are beyond the scope of this thesis, so it remains unknown how IBA affects targets between 300 and 500 meters. The trade-offs between survivability and lethality are also not part of this study, but these issues have an impact on SDM tactics and may be worth further study. This is discussed further in Chapter V.

4.   Probability of Hit by Firing Posture

The study also analyzes the effects of posture on marksmanship.   As seen above in Table 7, almost 95% of the observations come from the standard qualification postures, Prone Unsupported and Foxhole Supported. The Test Platoon constitutes about 10% of all observations, with a roughly uniform distribution of observations on all four postures. Almost all Kneeling and all Standing observations are from the Test Platoon.

Table 7.   Distribution of Observations by Posture

Level	Count	Percentage
PRONE UNSUPPORTED FIGHTING POSITION	14135	48.73%
FOXHOLE SUPPORTED FIGHTING POSITION	13362	46.06%
STANDING	780	2.68%
KNEELING	728	2.51%

As seen in Figure 27, there is a marked difference in the Probabilities of Hit between postures. The more stable postures, such as Foxhole Supported, are inherently more accurate than an unstable position, such as Standing or Kneeling. The chart shows the same decrease in PH as the target distance increases.   Interestingly, Kneeling, although less accurate than the other postures, does not demonstrate the precipitous drop in PH that the Standing posture does. On average, the Kneeling posture is about 12% less accurate than the other two firing postures, but these disadvantages diminish as target range increases to 300 meters.

Also interesting is that the PH for Kneeling at 150 meters (0.49) is not greater than that at 100 meters (0.51), as with the traditional postures. This may lend some insight as to the reason for a lower Probability of Hit. Errors caused by hasty trigger squeeze normally cause horizontal deviance, whereas errors caused by improper breathing causes vertical deviance. If the additional vertical target angle from F-type target at 100 meters to E-type has no effect, this could mean that a majority of the shooter-induced error results from trigger squeeze. If this hypothesis is correct, modified training may be one method to reduce the Kneeling disadvantages.

PROBABILITY OF HIT BY RANGE
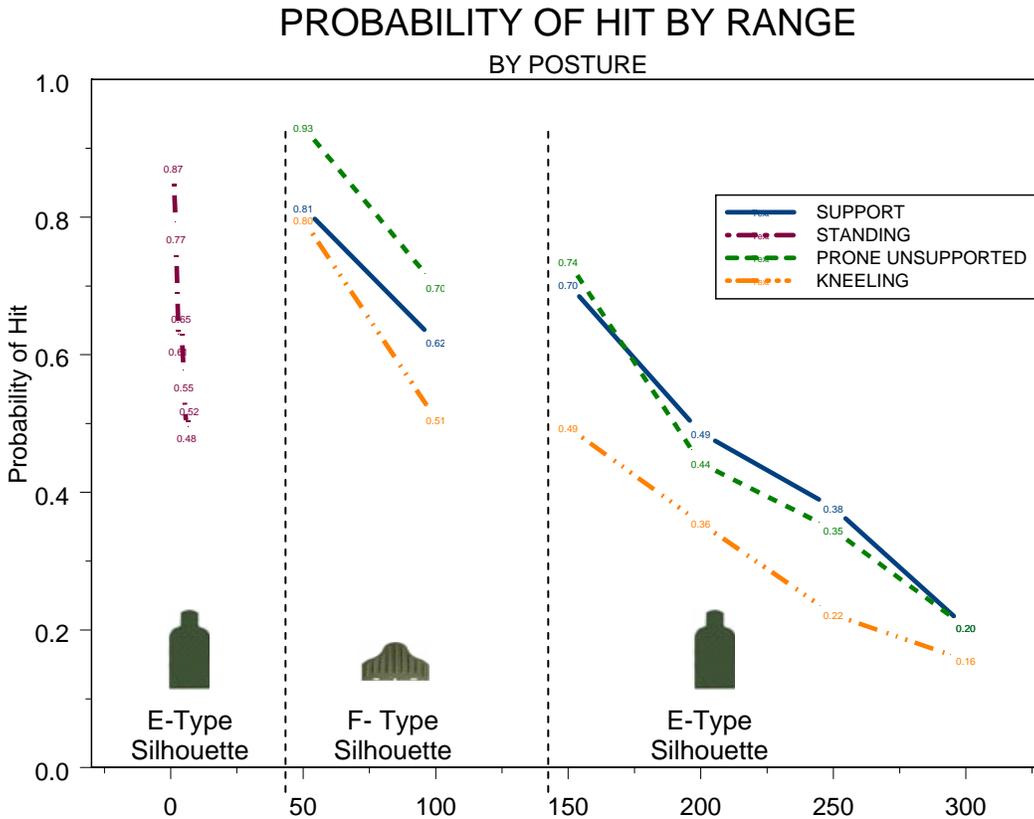
BY POSTURE

Figure 27.   Probability of Hit by Posture

A multi-comparison of the postures—excluding Standing—shows that Kneeling is indeed not equal to the Prone or Foxhole firing positions. At the α = 0.05 and α = 0.10 levels, the Chi-Square Test rejects the null hypothesis that the postures are equal.

5.   Probability of Hit by Weapon Type

As seen in Table 8, the average experience for the M203 rifle in years of service is roughly equal to that of the M16 rifleman. The M4 riflemen have significantly more service than their counterparts, on average 2.5 years experience. The senior leaders in a platoon and company normally carry the M4 Carbine, whereas the more junior riflemen carry the M16 and M203.

Table 8.   Distribution of Observations by Weapon Type

Level	Count	Percentage	Average Years of Service
M16A2/4 Rifle	21794	75.14%	3.97
M203 Grenade Launcher	1902	6.56%	4.09
M4 MWS Carbine	5309	18.30%	6.47

Figure 28 and Figure 29 break down the proportion of hits by weapon type. For both short range (less than 50 meters) and standard ranges (50 to 300 meters), the probability of hit is generally the same for any weapon used. The M4, because of its shorter barrel, will be inherently less accurate than a longer barreled M16 variant. (FM 3-22.9)
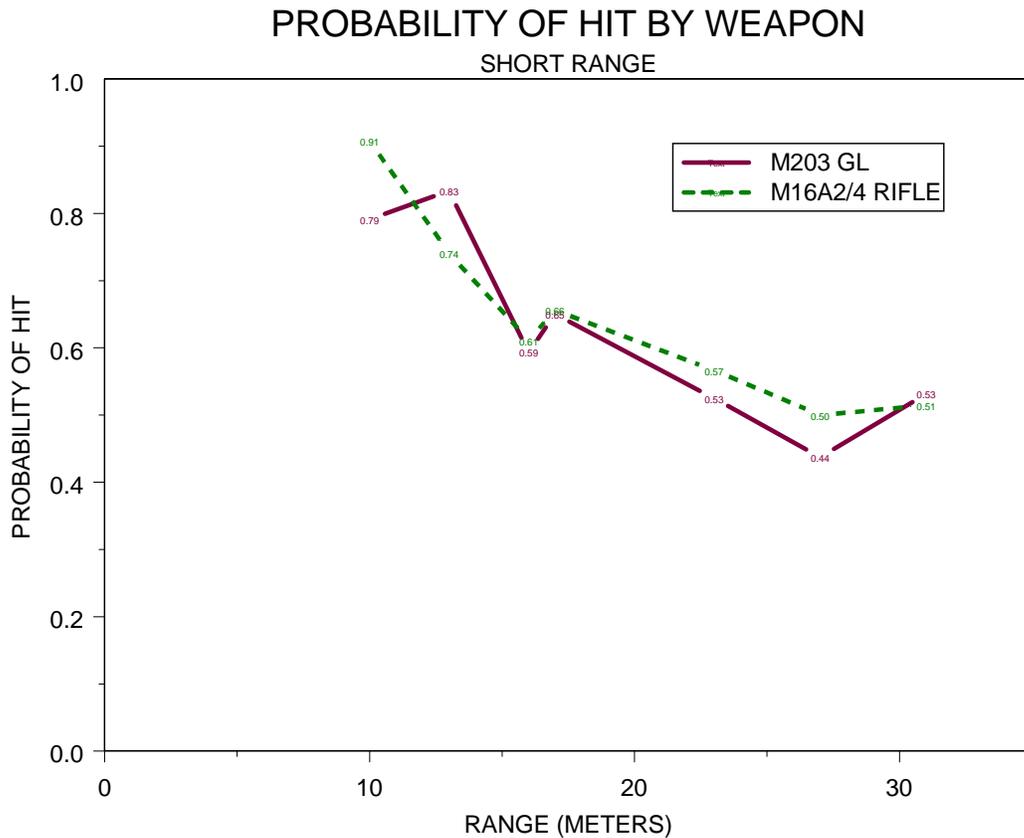
Figure 28.   Probability of Hit by Weapon Type—Short Range

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PROBABILITY OF HIT BY WEAPON
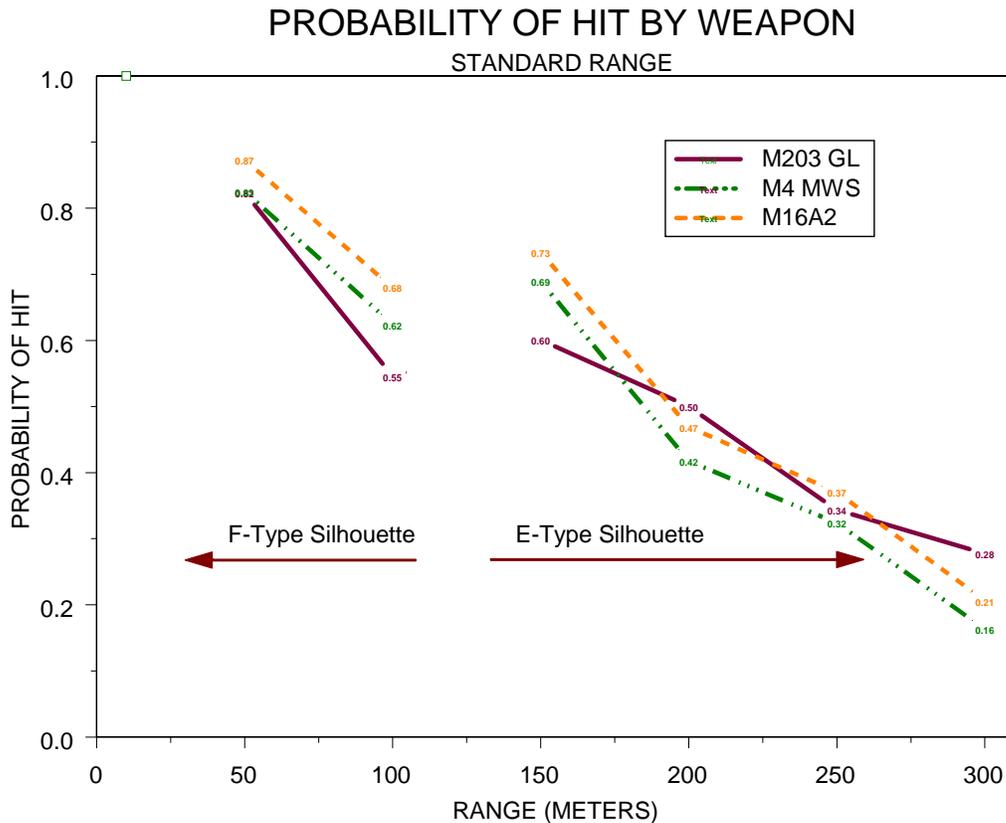
STANDARD RANGE

Figure 29.   Probability of Hit by Weapon Type—Standard Range

The differences in Probability of Hit for weapon types are significant. The Chi-Square Test (Appendix D) fails rejects the null hypothesis that there is no difference in Probability of Hit based on weapon type with *p*-value << 0.01. The multi-comparison test shows that there is significant difference between the rifles with the M203 GL and the other rifle types, but there is no significant difference between the M4 and M16 rifles. This Chi-Square Test fails to reject the null hypothesis that the Probabilities of Hit for the two rifles are equal with *p*-value = 0.6549.

The differences in Probability of Hit that resulted from the various rifle types defy a simple explanation. As noted above, the M4's shorter barrel is less accurate, yet other reasons may exist for the different findings. It is possible that

Soldier experience has a negative effect on the Probability of Hit. If the M4 rifleman are more experienced, and this experience negatively affects their accuracy, then the average Probability of hit will be lower for the M4 riflemen than for the M16 riflemen.

6. Probability of Hit by Aiming Device

How does the aiming device affect Probability of Hit? The majority of shooters, over 95%, used the standard ironsight. The M68 Close Combat Optic (CCO) is equipment currently available to the combat units. Even when available, the equipment is not uniformly used throughout the force, as was the case for the brigade's basic qualification. The Soldiers initially qualified with their ironsights, and then, if time and equipment were available, they requalified with the CCO. As a result, most soldiers either did not have a CCO issued or did not have time to requalify.

This was not an issue for the Test Platoon. They conducted a basic ironsight qualification on one day and then returned to conduct subsequent firings with the CCO. Even among the Test Platoon, there were not enough CCOs for all soldiers to dual qualify. Figure 30 shows that the limited number of observations in which the one soldier fires both systems prevents any definitive conclusion on the effects of the CCO. The Chi-Square Test fails to reject the hypothesis that the iron sight is equal to the M68 CCO. The data suggests that the M68CCO performs no better or worse than the Ironsight.

Table 9.   Distribution of Observations by Aiming Device

Level	Count	Percentage
IRONSIGHT	27741	95.64%
M68CCO	820	2.82%
OTHER	444	1.53%
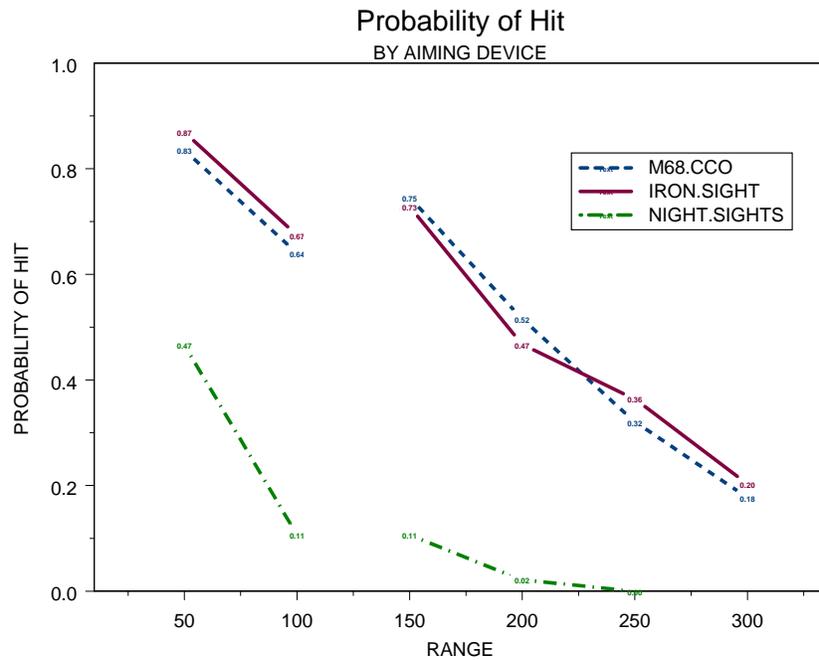
Figure 30.   Probability of Hit by Aiming Device—Standard Range

We now look at the same scenario applied for the nighttime aiming devices. As discussed earlier, little collection took place after dark. The Test Platoon did conduct a small set of night engagements, using night vision goggles and infrared aiming lasers. The seven firers that conducted this testing used their organic weapons systems with no additional lighting on the range. Those Soldiers with A/N-PEQ 2A lasers with infrared illuminators did not use those capabilities during the table. Ambient light conditions were not good, and this is a dominant reason the Probabilities of Hit are quite low. The observations should be considered a poor representation of night-time capabilities.

7.   Probability of Hit by Helmet

Does the Soldier's type of helmet have any effect on his Probability of Hit? Figure 31 shows a strong difference in the Probability of Hit due to the effects of helmets. As Table 10 shows, however, the number of observations with Advance Combat Helmet (ACH) are few when compared to the legacy system,

the Personal Armor System Ground Troop–Helmet (PASGT). This uneven number of contrasting observations does not support strong statistical analysis. Other unique factors might explain the difference in PH better than helmet type. The only test subjects with the new helmet are all from the same unit, 2nd Battalion, 54th Armor, that was preparing for combat deployment. The effects of the ACH are confounded with the effects of the unit type and MOS. Regardless, the Chi-Square Test rejects the null hypothesis that the two helmets were equal with a *p*-value << 0.01.

Table 10.   Distribution of Observations by Helmet Type

Level	Count	Percentage
Advance Combat Helmet	200	0.690
PASGT Kevlar Helmet	28805	99.310

PROBABILITY OF HIT BY HELMET
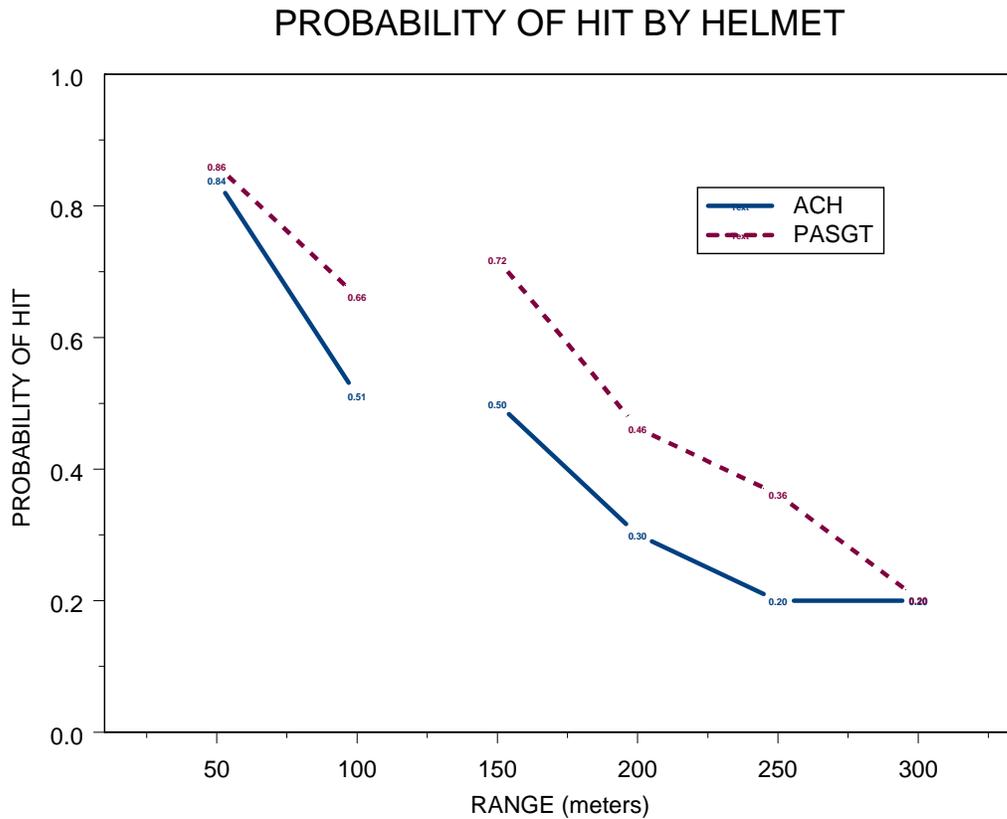
Figure 31.   Probability of Hit by Helmet Type

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8.   Probability of Hit by Soldier's Rank

Is there a difference in Probability of Hit by Soldier rank or experience? The test subjects came from an active maneuver brigade, with Soldiers of all levels of rank and experience. The lowest rank observed was an E-1 Private and the most senior rank was an E-9 Command Sergeant Major (for enlisted) and O-3 Captain (for officers). Officers of the rank O-4 Major and higher were not observed, as most of these personnel were issued a pistol and would not normally fire a rifle.

Table 11 shows that over 94% of the data is from enlisted servicemembers, either Soldiers serving their initial enlistment or Noncommissioned Officers (NCO). This distribution is typical of an Infantry Company, where a 129-man company has 5 officers, 31 NCOs, and 93 enlisted Soldiers. Figure 32 shows the results of separation by rank group. The Chi-Square Test fails to reject the null hypothesis that there is no difference between the shooting of enlisted Soldiers and officers with a p-value of 0.791. It also fails to reject the hypothesis that the rank groups (Soldier, NCO and Officer) shoot equally well at the α = 0.10 level. The results demonstrate no significant difference between rank groups.

Table 11.   Distribution of Observations by Rank Group Type

Level	Count	Percentage
SOLDIER	20518	71.03%
NCO	6650	23.02%
COMPANY OFFICER	1717	05.94%

Table 12.   Distribution of Observations by Enlistment Type

Level	Name	Rank Group	Count	Percentage
SPC	Specialist	Soldier	14504	50.00%
PFC	Private First Class	Soldier	4994	17.21%
SGT	Sergeant	NCO	3939	13.58%
SSG	Staff Sergeant	NCO	1440	4.96%
SFC	Sergeant First Class	NCO	1031	3.55%
PV2	Private	Soldier	940	3.24%
2LT	2nd Lieutenant	Officer	760	2.62%
1LT	1st Lieutenant	Officer	637	2.19%
CPT	Captain	Officer	320	1.10%
CPL	Corporal	Soldier	120	0.41%
UNK	Unknown		120	0.41%
CSM	Command Sergeant Major	NCO	80	0.27%
PVT	Private	Soldier	80	0.27%
1SG	First Sergeant	NCO	40	0.13%

PROBABILITY OF HIT BY RANGE

By Rank Group
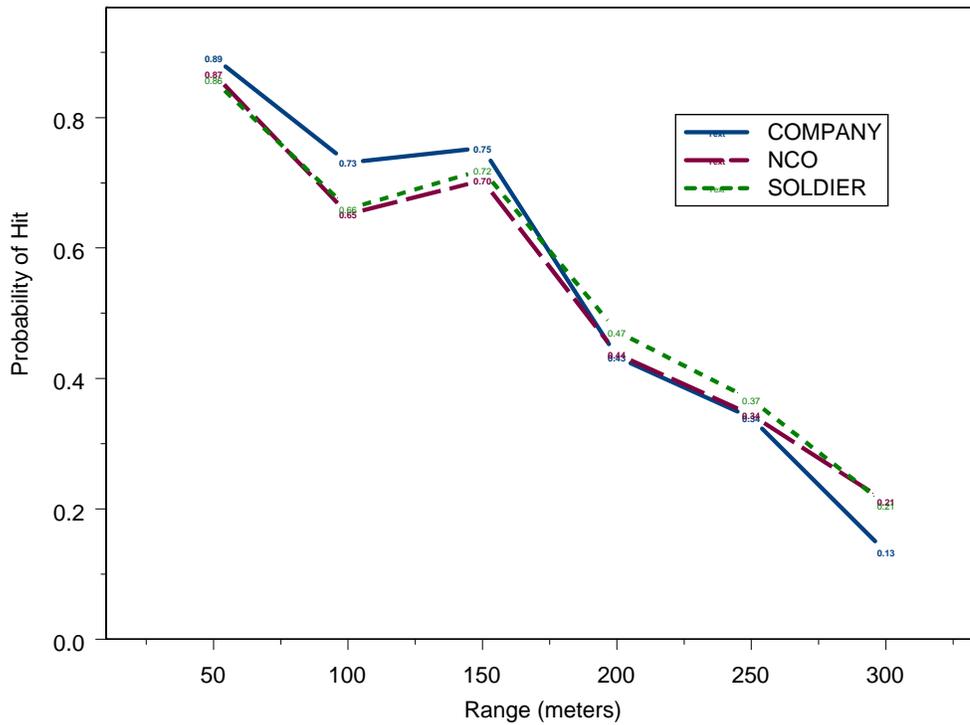
Figure 32.   Probability of Hit by Rank Group

9.   Probability of Hit by Military Occupational Specialty (MOS)

Do some Military Occupational Specialties shoot differently than others? We would expect Infantrymen to shoot better than those Soldiers in a supporting or service specialties, such as cooks or medics. The study observed a total of 42 different MOSs, a fair sample from the distribution of MOSs in a typical maneuver combat brigade.   The MOSs are aggregated into two categories: Combat and Combat Support.   The Infantry, Field Artillery, Air Defense Artillery and Armor MOSs are aggregated into the category Combat and all other MOSs into the category Support. The combat MOSs comprise 80.7% of the total observations and all of the short range observations. Almost half of the total observations are infantry, with 36.5%. All of the Test Platoon are MOS 11B—Infantry.

Table 13.   Distribution of Observations by MOS

Level	Count	Percentage
COMBAT	23408	80.70%
SUPPORT	5597	19.29%

Table 14.   Distribution of Observations by MOS Functional Area

Level	Count	Percentage
OTHER	920	3.17%
INFANTRY	10584	36.49%
FIELD ARTILLERY	9053	31.21%
AIR DEFENSE ARTILLERY	2460	8.48%
ARMOR	1548	5.34%

As seen in Figure 33, MOS does not appear to significantly affect the Probability of Hit. The probability of hit for each category is nearly identical, so close that the MOS type does not seem to be a first-order effect.   The Chi-Square Test p-value is 0.8519 and retains the hypothesis that the two MOS categories are the same at standard significant levels.   This is an interesting finding in itself—the Support Elements shoot as well as their Combat MOS comrades.

PROBABILIY OF HIT BY MOS TYPE
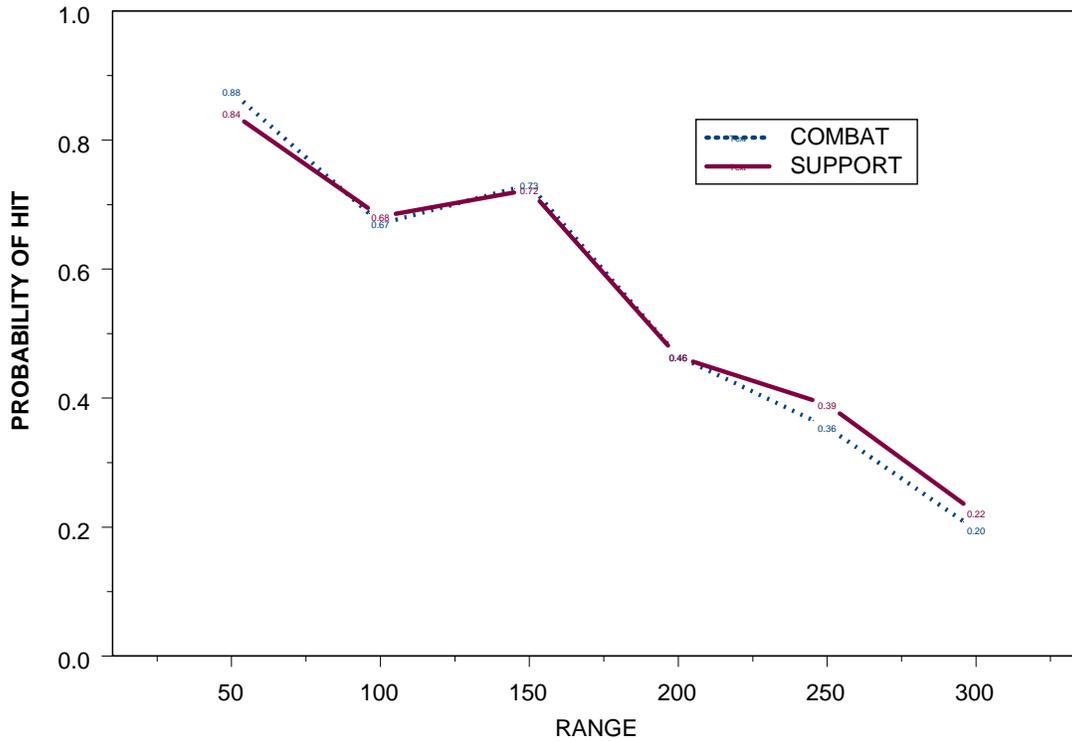
Figure 33.   Probability of Hit by MOS Group

When the data are separated into Infantry and Non-Infantry observations, as seen in Figure 34, there is a significant difference between the two groups, with a Chi-Square Test p-value = 0.0635. Infantry Soldiers do not shoot better than non-Infantry Soldiers. The Test Platoon also does not shoot significantly better than the sample population.   The Chi-Square Test fails to reject the hypothesis that the two samples are different with a p-value of 0.2096.

PROBABILITY OF HIT
BY INFANTRY / NON-INFANTRY
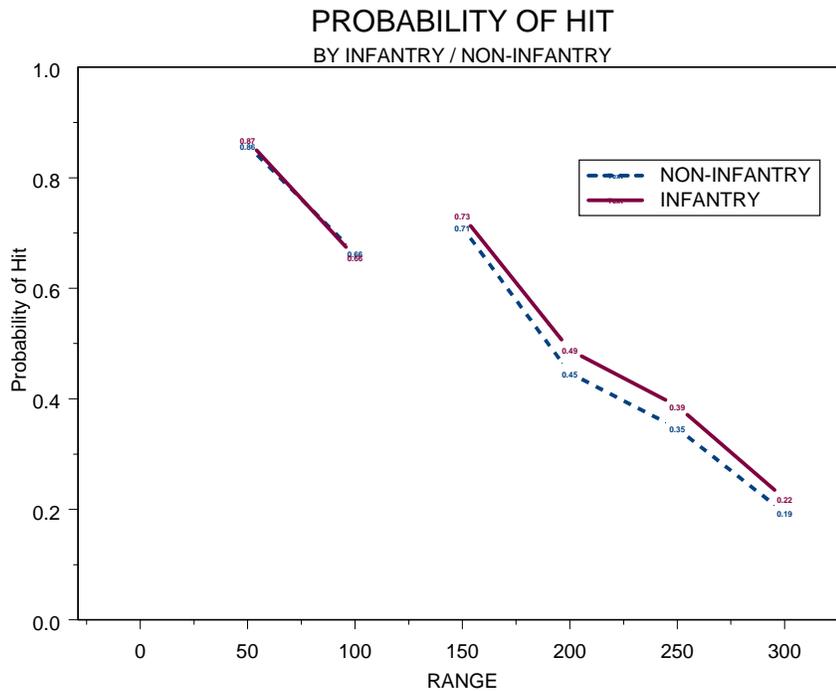
Figure 34.   Probability of Hit by Infantry and Non-infantry

When the data are separated by the Soldier's battalion type—Infantry, Armor, Field Artillery or Cavalry—differences begin to appear.   As seen in Figure 35, the infantry battalion has a higher Probability of Hits than other battalions. The Chi-Square Test rejects the null hypothesis that all the battalions shoot the same with a *p*-value << 0.01. The Infantry Soldier's shot slightly better than their non-Infantry brethren. The differences are between Infantry and the Armor and Field Artillery are significant, however, and the Chi-square Test rejects the hypothesis that the two populations are equal with a *p*-value << 0.01. The same is not true for the Infantry and the Cavalry Battalions. The Chi-Square Test fails to reject the hypothesis that the units shoot equally well with *p*-value = 0.7461.

PROBABILITY OF HIT OVER RANGE
BY MILITARY OCCUPATIONAL SPECIALTY TYPE
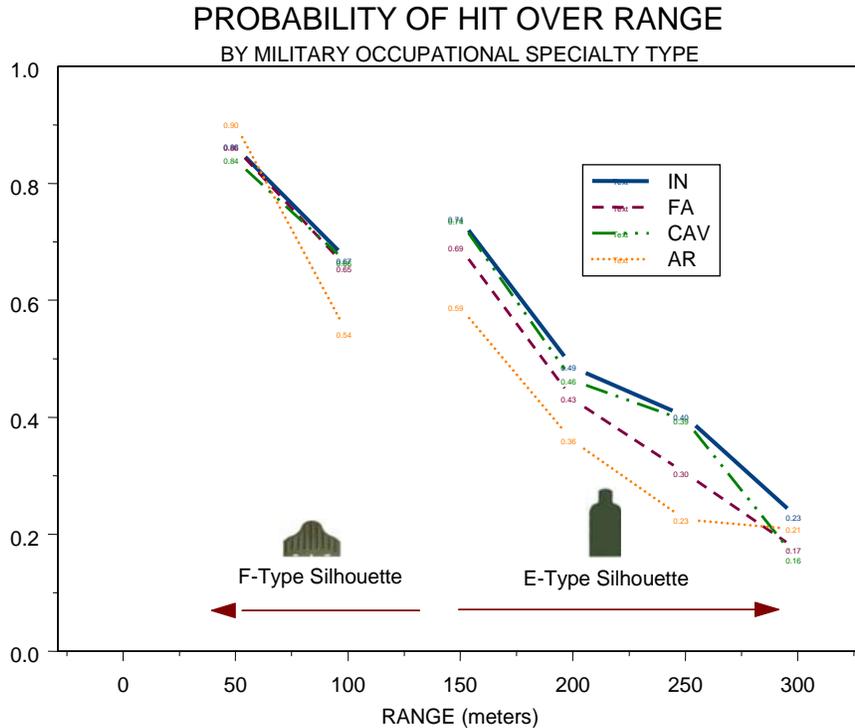
Figure 35.   Probability of Hit by Battalion Type

C.   SUMMARY

The statistics in this chapter are simple two-dimensional profiles of the data. Although it is easy to state that one piece of equipment is significantly more accurate than another piece of equipment, the complete effects of equipment and posture are more complex than these charts and statistics can reveal. The correlation matrices show where some variables contain much of the same information and where they may impact the Probability of Hit. This is still not a complete picture of how all variables interact. To gain this complete picture, one can create a complex logistic regression model of the data.

Regression models may explain much of what we observe, but they cannot explain everything. Some Soldiers are naturally talented riflemen, and no measurable data can explain the reasons. Two Soldiers with exactly the same equipment, training, and target scenario will not shoot exactly the same. Striving to explain these reasons can create a model that explicates the data too fully. A

statistical model that over-fits the original data has excellent prediction power for the one sample, but it may have poor capabilities on independent samples. There is a balance between predicting too much and not enough.

Chapter IV discusses the approach to creating the logistic regression models. It also evaluates the competing models and chooses a model that is both precise to the significant variables and accurate to the independent data sets.

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IV. DATA ANALYSIS

> All models are wrong, but some are useful.
>
> —George Box

This chapter

- Describes the methods and techniques used to create the probability of hit model.
- Tests several models for goodness of fit using the Hosmer-Lemeshow Test.

A. SELECTING APPROPRIATE DATA

1. Non-Qualifying Observations

The majority of the data are observations from the Qualification Record Fire tables. To qualify with the rifle, Soldiers must hit 23 or more of the 40 targets in Tables 1 and 2. If the Soldier did not meet this minimum standard, the score was discarded and the Soldier tried again. Nearly one-third of the 29,005 observations are from non-qualifying iterations. In the data set, they represent observations with learning effects—observations that will tend to improve from observation to observation.

Should the unqualified data be part of the modeling data? Using the non-qualifying data would introduce bias into the model that would under-represent the skills of the qualified riflemen. If the Army does not employ these unqualified Soldiers in combat, why use unqualified Soldier data to model Soldiers in combat? Figure 36 shows the difference in the Probabilities of Hit for qualifying and non-qualifying iterations. The Chi-Square Test rejects the hypothesis that the two subsets are equal with a p-value $<< 0.01$. The model therefore does not include information from the non-qualifying iterations.

PROBABILITY OF HIT BY RANGE
BY QUALIFYING OR NON-QUALIFYING RUNS - WHOLE POPULATION
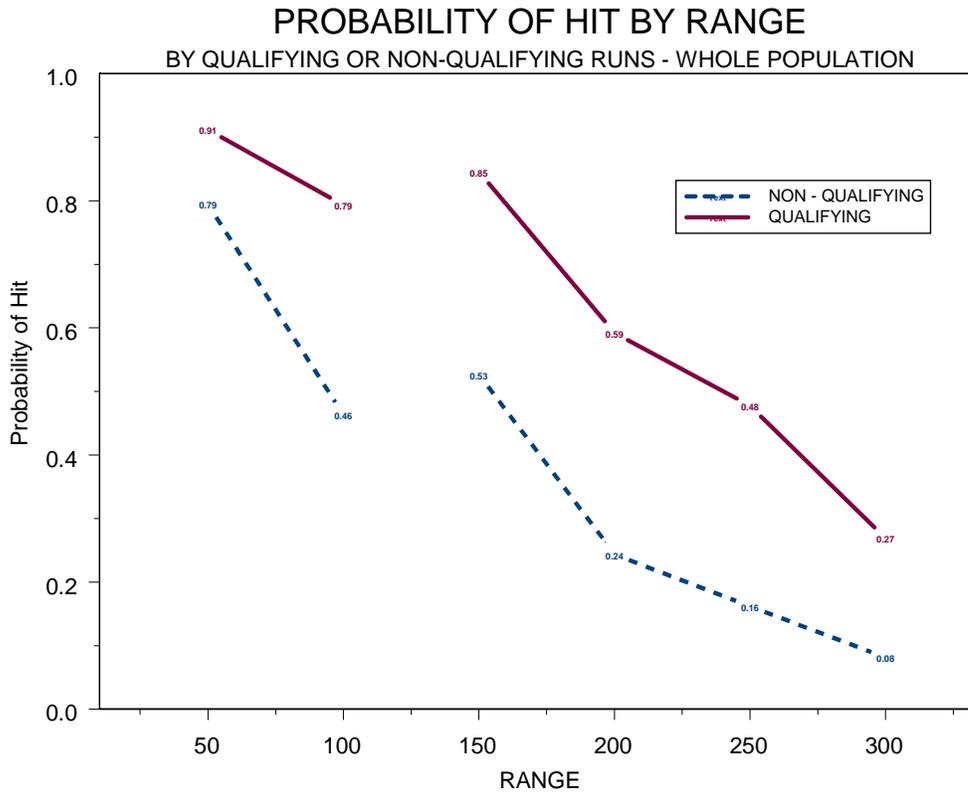
Figure 36.   Probability of Hit by Qualifying Iteration

By rejecting the unqualified data, we introduce two assumptions into our model. First, the resulting model would only be used to model qualified rifleman. The model would not apply to Soldiers in training. Second, the model assumes that the qualifying iteration is not a fluke. This means that the Probability of Hit does not change over time, due to skill deterioration or fatigue.

2.   Day and Night Effects

Fewer observations were taken during night conditions. The Soldiers made sincere efforts during those runs, but the results did not meet current qualifying standards (FM 3-22.9, 2004). Excluding these observations makes the remaining data easier to model but also reduces the model's usefulness. The goal is to model the rifleman during both day and night, but the current data

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inadequately represents rifleman nighttime capabilities. This, however, does not invalidate the night time data. Having some predictive capabilities for nighttime is better than having none at all. The night time data are therefore included in the modeling set. The effects of darkness appear as the effects of the nighttime aiming device, since ambient light measurements are not part of the dataset

3.   Test Platoon Sample versus Entire Sample

How much data are sufficient for the modeling? What are the risks in modeling with only part of the data? The Test Platoon contributes 3,470 observations, 2,930 from qualifying or alternate. The Test Platoon also contributes most of the Kneeling observations and all of the Standing, Short Range, and Night observations. Any analysis of Posture or Body Armor must use the Test Platoon data. On the other hand, the Test Platoon is only 10% of the data, and ignoring the other 90% of the available information may increase the model's error. The Test Platoon has more levels of the posture and equipment, but no variation in MOS or unit variables. In contrast, the entire sample has more levels of the MOS and Battalion type, but these factors are not the focus of the study. Furthermore, the initial analysis shows that these factors are insignificant or marginally significant. The entire sample set is large enough to conduct a bootstrap method—building a model from random subsets of the total data—very well, but fitting a model to all 29,005 observations is not feasible with the computers available.

The computing capabilities became the limiting factor. The study had access to desktop and laptop computers. Creating multiple regression models with possibly hundreds of variables on 29,000 observations was beyond the machine's memory capabilities. The Test Platoon became the data set for the model.

B.   LOGISTIC MODELING

1.   Stepwise Logistical Regression

How many factors should the model contain? A very simple model is one that uses only target distance to determine Probability of Hit. Table 5 from Chapter III is one such model. This model is easy to implement, but it is not sensitive to other variables, such as posture or equipment. A more complex model, one with many factors, such as posture, wind speed, body armor, or aiming device, offers more flexibility in scenario parameters, but such a model is more difficult to implement inside a simulation.

This study produced several models, but will discuss only three. The simplest, Model #1, uses only target range and shooter posture. It has five degrees of freedom, but it accounts for only 1% of the variability in the Test Platoon data. A slightly more complex model, Model #2, introduces target exposure time and target angle as predictor variables. This second model has 10 variables and accounts for 7% of the observed variance. It does not appear that models with simple predictive factors are going to have sufficient predictive power. The models need to be more complex.

The issue of model complexity was solved with Mixed Stepwise Regression (Sall, Creighton, and Lethman, 2005) and implemented in JMP IN Release 5.1.2. The level of significance for each factor to enter or leave the model was $p = 0.10$.

The model began with the following factors:

Shooter Variables: Height^2, Equipment Weight^2, Equipment Weight Ratio^2, Years of Service^2, Weapon Type, Body Armor Type, Aiming Device, Posture

Target Variables: Range^2, Target Angle^2, Single-Multiple

Environmental Variables: Temperature^2, Wind Speed^2, Wind Deflection^2

Plus: Interaction between all first order variables.

The superscripted variables correspond to both first and second-order effects (e.g. Height^2 → Height + Height*Height). The model introduced first and

second-order variables of all continuous variables plus the interactions between all first-order terms. For example, Height + Height*Height + Height*Weapon + Height*Body Armor + Height*Equipment Weight + etc. There were a total of 114 possible coefficients for the stepwise regression to include. Of these, only 38 were significant in the presence of the others at the $p = 0.10$ level. The 38 degrees of freedom accounts for 28% ($R^2 = 0.2825$) of the variability in the 2,240 observations. The negative log likelihood is 427, with a p-value < 0.01. This rejects the hypothesis that the model provides no predictive improvement.

Appendix A lists the model factors and their significance. Interpreting the coefficients from this report is complex, as JMP automatically creates dummy categorical variables that may be either {0,1} or {-1,0,1} that reverse the effects of the listed coefficients. The significance of the variables is much easier to interpret. The majority of the variables have a large significance. The right column of Appendix A shows the p-value associated with the hypothesis that the coefficient is equal to zero, $\beta_i = 0$. All of the 2nd order terms and interaction terms have p-values < 0.05. As stated above, this model uses $p = 0.10$ to enter and to leave the model. It is interesting that the significances are either greater than 0.10, and they are not included in the model, or less than 0.05. There are no factors with p-values between 0.05 and 0.10. This point lends further credibility in the resulting model. All factors includes in the final model are more significant than the minimum standard requires.

One note about the $R^2 = 0.28$. This number is deceivingly low. It means that with all 38 variables, regression modeling explains only 28% of the variance in the data. R^2 values tend to be low for binary data. The meaning of R^2 in this case is that equipment, posture and all other factors make a difference, but not as much as the "intangible" variables discussed earlier: training, concentration, confidence, and leadership. These intangible factors comprise the other 72% of the variation, but they are the most difficult to measure. The low R^2 might not be good for this study, but it adds background to the higher purpose of understanding rifle marksmanship and Soldier performance. Improving rifleman

capabilities has less to do with the tangible pieces of equipment and more to do with training and leadership.

2.   Hosmer-Lemeshow (HL) Test

After the regression was complete, the next step is testing the model for goodness of fit.   The Hosmer-Lemeshow Test is an established method to determine goodness of fit for a logistic regression model with a large number of factors (Hosmer and Lemeshow, 2000).   The test determines if the model's predicted responses are statistically close to the proportion of actual responses. Using the weather forecaster analogy again, the Hosmer-Lemeshow Test determines if it rains about 80% the time the forecaster says "80%."   The test sorts in ascending order the observations according to the model's prediction of success, $\hat{p}$.   It bins the observations into g groups, normally 10, and calculates the average $\hat{p}$ for each group, $\bar{\pi}$.   The test then compares the observed number of success in each group to the expected number successes.

$$\hat{C} = \sum_{i=1}^{g} \frac{\left(O_i - N_i \bar{\pi}_i \right)^2}{N_i \bar{\pi}_i (1 - \bar{\pi}_i)}.$$

Equation 3:   The Hosmer-Lemeshow Statistic (After Hosmer and Lemeshow, 2000)

where O_i is the number of successes the ith group, N_i is the number of observations in the ith group, and $\bar{\pi}_i$ is the average estimated probability of success in the ith group. The sum of the squared differences of each group divided by the variance is the C-statistic.   A lower C-statistic corresponded to a better fitting model.   A C-statistic of 0.00 means the model accurately predicted all observations.

Hosmer and Lemeshow prove that asymptotically the C-statistic follows the Chi-Square distribution (Hosmer and Lemeshow, 1980) and accurately tests the hypothesis that the predicted Probability of Hit is statistically close to the observed proportion of hits. The final product of the test is an assessment on the

Goodness of Fit. A *p*-value < α, such as *p*-value < 0.10, corresponds with a model that poorly fits the observed data. The Chi-Square probability α < *p-value* < 1.00 corresponded to a model that closely fits the data it predicts.

C. TESTING THE MODELS

Figure 37 displays the result of the HL Test on the three models. All models use the same data. The table lists model identification number, the input parameters by category, the degrees of freedom/input variables used in the model, the Hosmer-Lemeshow Test C-statistic, and the model's goodness of fit measure.

Model #1, the model with only target range and shooter posture, does not sufficiently fit the data according to the HL test. Model #2 does better, with a *p*-value of 8.5%. This means that if the model is correct, there is only an 8.5% chance of seeing data as discordant as the observed data. The full outline of Model #2 is in Appendix A. Model #3, with nearly all recorded continuous and categorical variables, does the best in the Hosmer-Lemeshow Test. There was a 19.7% chance that if the model is correct, we would see data such as extreme as the observational data. The full list of model coefficient estimates and factors is in Appendix B. Model #3 is henceforth used to describe effects of the equipment and posture.

One note about statistical versus practical significance: Model #3 best predicts the observed data with all available factors. This does not mean #3 is the best model for all uses. It may predict Probability of Hit adequately well for one use, but may require too much time to collect and maintain for another simulation. Model #1 and #2 may be statistically insignificant, but may be practically significant for other uses. The user is the only one who can truly determine if a test has practical significance.

Table 15.   Model Description and Significance

Model	Input Parameters		df	C-Statistic	*p*-value
1	Shooter:	Posture	5	31.56	0.000
	Target:	Range			
2	Shooter:	Posture	10	13.88	0.085
	Target:	Range, Target Angle & Exposure Time			
3	Shooter:	Posture, Height, Equip Weight & Ratio, Years of Experience, Weapon, Aim Device, Rank Group	38	11.022	0.197
	Target:	Range, Target Angle, Exposure Time, Single or Multiple			
	Environment:	Wind Speed, Temperature			

HOSMER-LEMESHOW TEST
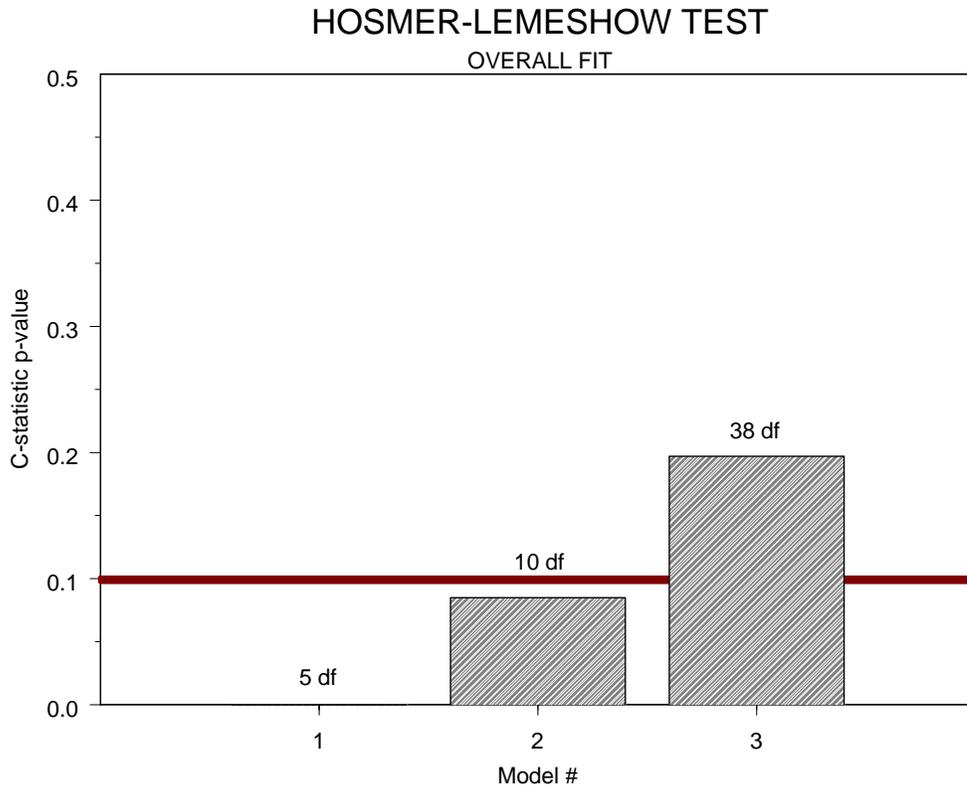
Figure 37.   Hosmer-Lemeshow Goodness of Fit Results

D.   SIGNIFICANCE OF FACTORS

Another utility of the Hosmer-Lemeshow test is that it determines goodness of fit for different treatments of individual factors. In this way, it is possible to test whether a model predicts well for specific factors, such as IBA, the M4 Carbine, or the Kneeling Posture. The following charts plot the average Probability of Hit versus the actual proportion of hits for the different levels of Body Armor and Posture. The tables following the charts list the Hosmer-Lemeshow Test goodness of fit *p*-value for the model at each level.

1.   Body Armor

Figure 38 shows the plotted difference in the levels of body armor. As discussed in Chapter III, these differences are statistically significant, with the Chi-Square test rejecting the null hypothesis that the two types of body armor are equal. The dashed lines in Figure 38 represent the model's predicted Probability of Hit. The Hosmer-Lemeshow Test rejects the hypothesis that the model is a good fit for IBA at the α = 0.10 level with a *p*-value of 0.048. It fails to reject the hypothesis for non-IBA shooters with a *p*-value of 0.297.

These probabilities are remarkable because Body Armor is not an input factor in the prediction model. Both the actual and predicted data show significant differences between shooting with and without body armor. In the model, however, knowing body armor is not important if other variables are known. Body armor is not significant in the presence of other known variables. This offers a good explanation why the model scored well in the HL test for all data but does not score well for the subset of observations with IBA—the model did not use IBA as a predictor variable.

PROBABILITY OF HIT BY RANGE
ACTUAL vs PREDICTED- DAY & NIGHT TABLES
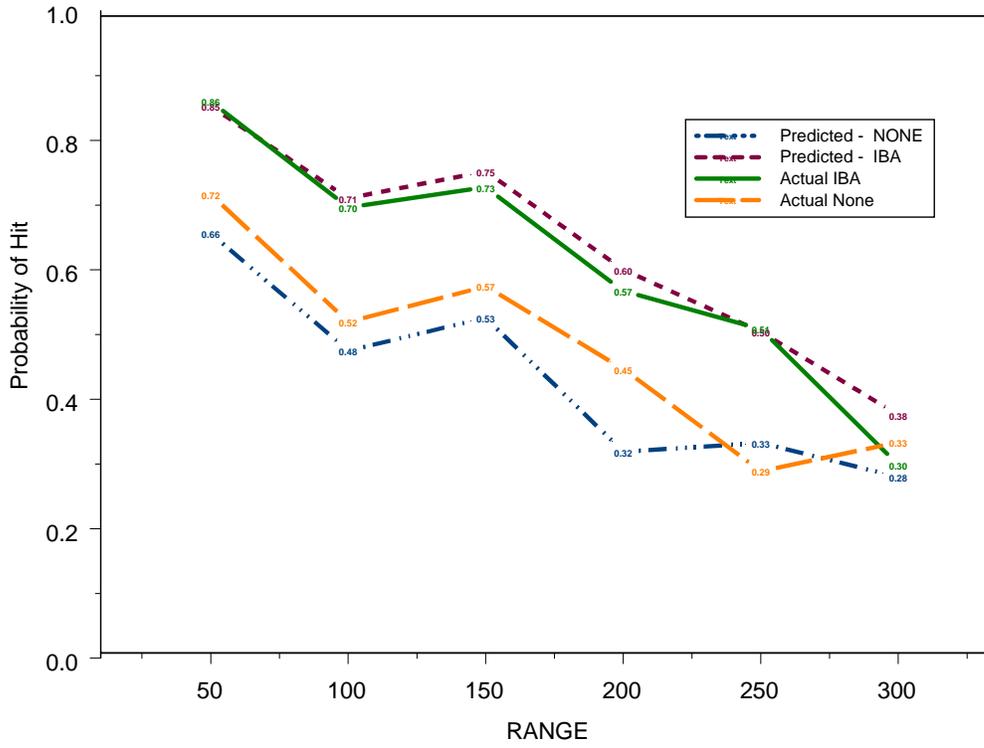
Figure 38.   Actual versus Fitted for Body Armor Type

The effects of Body Armor are conclusive. The Chi-Square Test rejects the hypothesis that IBA and No IBA are equal with probability p = 0.006. Figure 39 shows how those Probabilities of Hit change when the night observations are removed. The differences are still there, but outside of 200 meters, the results are not as definitive. The non-IBA firers shoot better than the IBA firers at 200 and 300 meters. The predicted Probabilities of Hit for Model #3 are also graphed in dashed lines to show the smoothing required. The model does not show the interaction of the observed data.
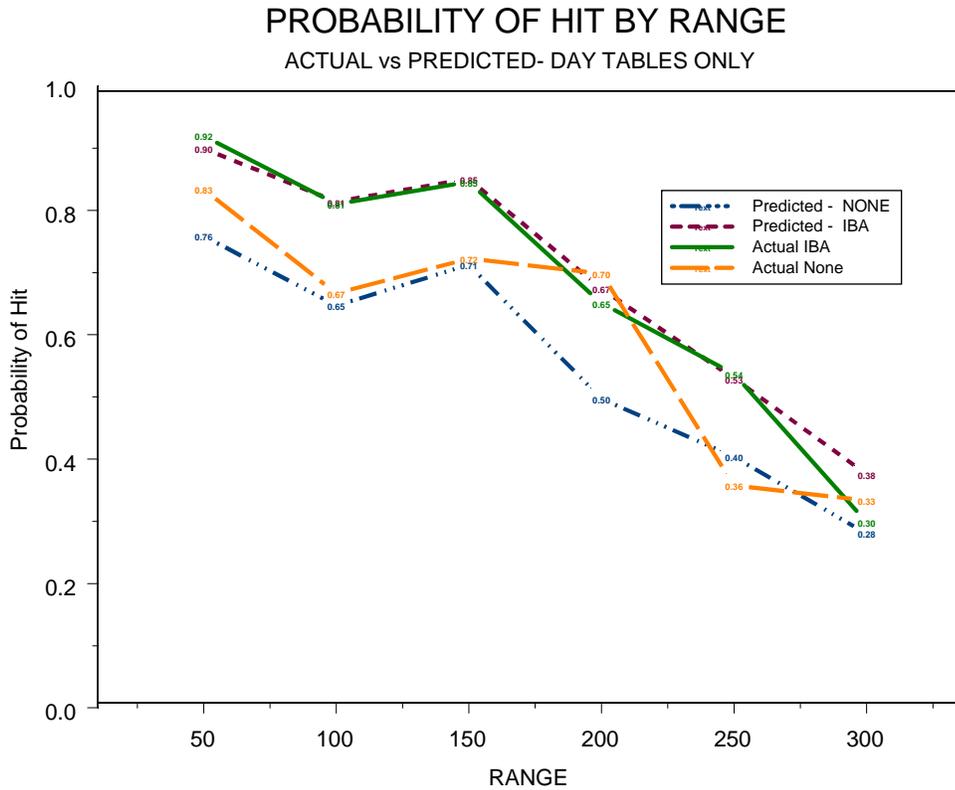
Figure 39.   Actual versus Fitted for Body Armor Type—Day Tables Only

Table 16.   Model Fit to Body Armor

Pr(Fit) IBA	Pr(Fit) No Body Armor	Pass All at $\alpha = 0.10$
0.048	0.297	No

2.   Posture

The model uses posture to determine Probability of Hit. As seen in Figure 40, the model generally fits each posture. The Foxhole posture has the worst fit, and the HL test *p*-value of 0.105 confirms this. What is reassuring is that the model finds significant effects for each of the postures and uses those postures to measure interactions.

The interactions between posture and other variables are complex. Prone, Foxhole and Standing postures with Years of Service had a positive effect

on Probability of Hit. As experience increases in these postures, Probability of Hit also increases. Soldiers with more experience shoot better from the Prone, Foxhole and Standing positions. The opposite happens with Kneeling. While Kneeling, the Soldiers with less experience shoot better than Soldiers with experience.

More interestingly, in the Prone, Standing, and Foxholes postures, Probability of Hit decreases as height increases. PH decreases on the order of one percent for every inch of height. This means that even with the issues of foxhole depth being a problem for short Soldiers, tall Soldiers do not have an advantage. The opposite was true for the Kneeling posture, where every additional inch of height is an advantage. The advantages are much more pronounced, where every inch above 70 inches gives a 16 percent advantage.

The model contains significant interactions between posture and both weapon type and total equipment weight. Most significant is the interaction between posture and total equipment weight. The interaction is between standing and equipment weight. As equipment weight increases, Probability of Hit decreases. This is intuitive—the weight of the equipment adds instability to the rifleman's arms. This should be most pronounced in the least stable posture, Standing.
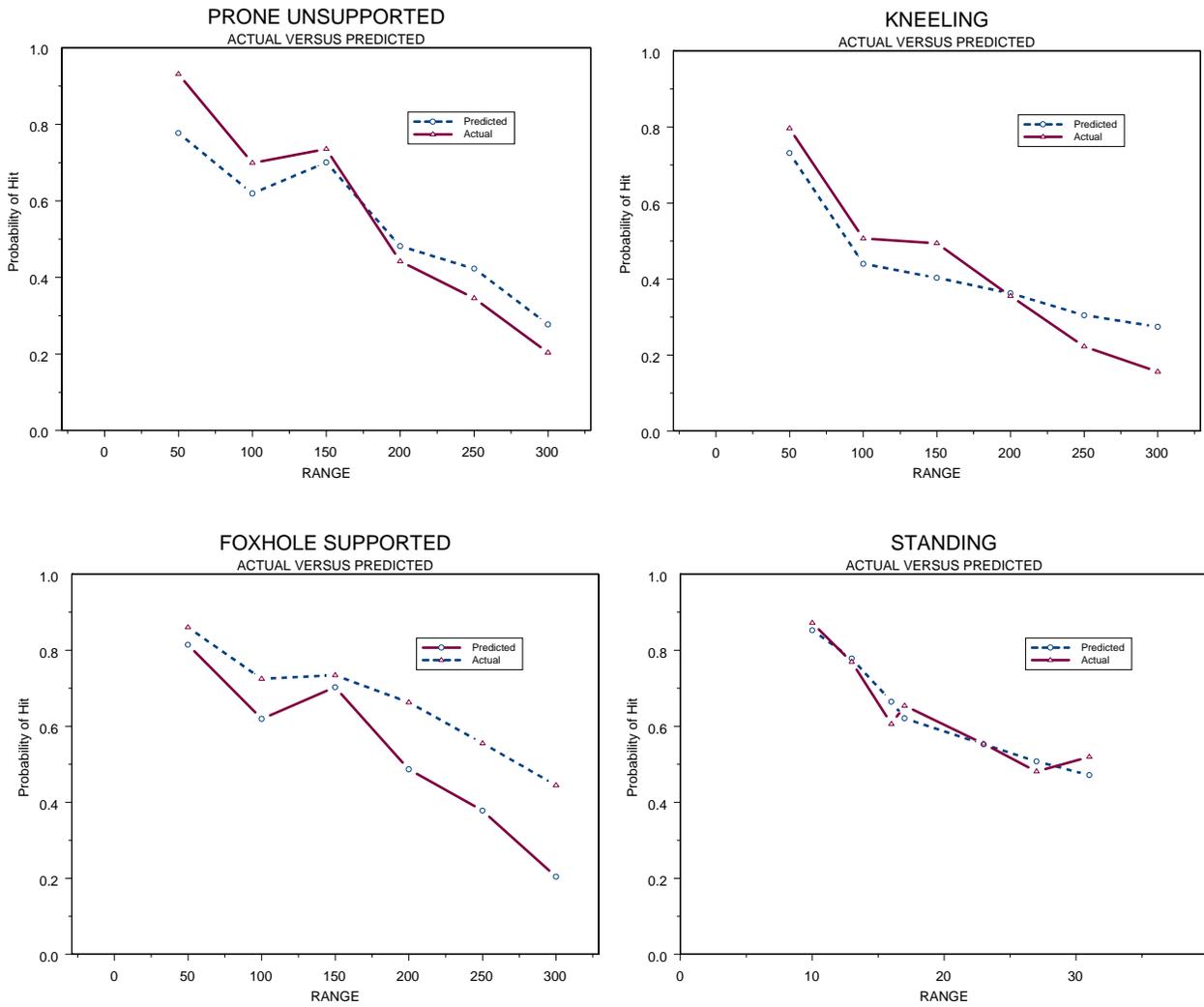
Figure 40.   Actual versus Fitted for Posture

p-value PRONE	*p*-value FOXHOLE	*p*-value STANDING	*p*-value KNEELING	Pass All at α = 0.10
0.857	0.105	0.357	0.436	Yes

Table 1:   Model Fit to Firing Posture

E. SUMMARY

The model produced with the observational data is statistically significant. The Hosmer-Lemeshow proves the model's validity at the α = 0.10 level for one level of body armor and four levels of postures. These findings, however, are not important.

The important findings are the insights this model provides into how equipment and posture interact to influence rifleman lethality. These insights lead to better understanding of the rifleman's strengths and weaknesses. Understanding his strengths and weaknesses should lead to improvements in equipment and tactics. Those improvements save lives. This is truly important.

The next chapter discusses the ramifications of the insights revealed during the study. It outlines areas of improvement for both equipment and training of riflemen. It concludes with a discussion of the study's lessons learned and opportunities for follow-on research.

V. CONCLUSION

Scientists can predict with some precision how technological improvements in weaponry will pay off on the battlefield. In both the Gulf War and the Iraqi War, the Iraqis possessed modern weapons. They simply did not know how to employ them. Technology will do little for the badly trained. In the end, technology is a tool. Only training can enable the soldier or marine to use the tools of war effectively.

(Murray and Scales, 2003)

This final chapter

- Discusses tactical insight of the analysis.

- Introduces areas of follow-on work available.

- Provides a design of experiment to strengthen the existing body of data and subsequent model.

A. TACTICAL INSIGHTS

1. Effects of Body Armor

a. Squad Designated Marksman

The model does not show a significant interaction between target range and IBA. The trend in the data, however, does show a trend between body armor and target distance, and the implications of such an interaction could be significant on the Squad Designated Marksman (SDM). The Squad Designated Marksman is to maneuver with his rifle squad and engage targets from 300 to 500 meters. If there is a negative effect from body armor, this equipment could possibly make him a less effective marksman at these longer ranges. One option to overcome this would be to employ SDM with body armor and be less effective. A better option may be to modify the IBA, and develop a SDM training regiment to reduce the negative effects of body armor.

The first option is already occurring. Responders to the survey in Appendix C write of "never [shedding] their body armor in a combat situation." (Response 3.12) The Soldiers trust the equipment and understand that it stops bullets. At this point in the Global War on Terror, it would be very difficult to convince a Soldier not to wear body armor. If given a choice, SDMs will most likely choose the survivability of IBA over perceived benefits in Probability of Hit. On the other hand, the responders wrote of specific individuals, namely snipers, removing their body armor for an operation. Snipers, however, unlike SDMs, do not maneuver with rifle squads, and if they remove body armor, it is likely for the improved stealth and comfort while in a hide position and not for the added lethality.

The second option, redesigning the Interceptor Body Armor, is an option that could improve lethality without sacrificing survivability. The main issue with IBA is that the body armor decreases the shoulder pocket Soldiers normally use for seating the buttstock of the weapon. The decreased pocket is less stable—or it feels less stable—and Soldiers perceive that it reduces their ability to form a stable firing position. It is possible that a redesign of the IBA shoulder portion, one that better stabilizes the buttstock, could mitigate the negative effect of IBA.

Employing the SDM with Body Armor does not mean that he will have zero effect on the battlefield. The data shows that body armor has little to no negative effect at ranges less than 200 meters. In this sense, the SDM will have the same capabilities at short range as his peers. Body armor may become an issue when the SDM transitions from conventional ranges (10-200 meters) to longer ranges (300-500 meters). At these ranges, the data suggests that body armor may have a negative impact. No data in this study estimates these impacts accurately. This study does not analyze the issues of SDM effectiveness versus his survivability. If a SDM does wear IBA, and this cause him to be less lethal, how does this affect unit performance? Agent Based Modeling (ABM), with the support of this study's Probability of Hit model, could

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provide insights into this question. This study suggests that there is a difference, and that this difference changes over the distance of the target. What is not known is how these differences change with posture.

b. Body Armor Limitations

The dataset contains contrasting observations for Soldiers with and without body armor in both the Prone and Standing postures. The study does not have contrasting data for IBA versus non-IBA in the Foxhole or Kneeling postures. This limits the conclusions of the body armor's effects over all postures. Testing body armor with these two postures should provide a deeper understanding of the impact on all postures.

In addition to multiple postures, the model needs data from Soldiers who trained without body armor. All Soldiers in this study conducted pre-marksmanship instruction with IBA. The effects of body armor may be confounded with the effects of this training. Data with contrasting training would provide a better understanding how body armor and training affect Probability of Hit.

2. Effects of Posture

As discussed above, effects of equipment are interlaced with the effects of posture. The stepwise regression does not find a significant interaction between posture and body armor, but it does find significant interactions between posture and several other equipment factors. In particular, the model finds a significant interaction between total equipment weight and posture.

The survey responses in Appendix C have several references to the weight of the body armor and posture. One response said that body armor "is a problem when firing from the prone, zeroing, qualifying or long distance shots (outside of 250 meters)." (Response 1.12) Other Soldiers disagreed. The survey does not ask for Soldier height or weight, and it is not possible to determine if Soldiers of different dimensions respond differently. The responses do have a general theme, and that is that the body armor influences firing posture choices.

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A rifleman chooses a firing posture based on the threat, security, and mission tempo of a situation. Soldiers may choose a lower posture, such as the Prone position, attempting to minimize their own risk to enemy fire. The Prone is a good posture for avoiding fire, but it is not advantageous to delivering aimed fire, especially in the presence of low vegetation. The alternative is to rise up to see better, which before IBA meant exposing the critical organs of the chest and torso. That is not so much the case now with IBA. Ballistic body armor reduces the risk of a lethal hit. The survey data suggests that rifleman with body armor may be more likely to fire from the kneeling position. They do so because it often offers better visibility of terrain and allows quicker movement. Equipment affects behavior, and Soldiers with IBA may be more likely to use the Kneeling posture.

This study does not look at rifleman behavior or decision making. The models, however, can quantify the effects of that posture choice. This family of models allows parent models to examine the effects of Soldier posture on larger-scale tactics and unit measures of performance. For example, a parent simulation may show that a unit can seize a urban area faster and with fewer casualties when the individual Soldiers with body armor use Kneeling instead of Prone firing postures.

Quantify the utility of Kneeling posture is now possible. Soldiers in the Kneeling posture have a Probability of Hit that is less than but comparable to the Prone or Foxhole postures. The Soldiers in this study were not formally trained in the Kneeling position. How well would they perform if they received the similar formal training as the Foxhole and Prone positions? Estimating final performance levels with the current data is not possible, but the Kneeling posture may offer equal lethality with better mobility than the traditionally trained postures.

Soldiers will fire from the Kneeling position if the situation requires. Current training doctrine treats the Kneeling position as advance techniques—it is recommended but not required (FM 3-22.9). This typically translates into neglected or poorly resourced training, as it is not specifically outlined in resorting

documents (DA PAM 350-38, 2005). The aggregate result is that in combat, Soldiers use a firing posture without formal training.

Incorporating the Kneeling posture into standard rifle qualification, or replacing Foxhole posture with Kneeling altogether, can capitalize on the advantages of body armor. Training in the Kneeling posture supports offensive operations in a manner that the static Foxhole posture does not. It is faster to transition from static firing to forward movement from the Kneeling posture than from the Foxhole or Prone position. There is a place for fighting position techniques, but current expeditionary operations in the Global War on Terrorism make mobile firing techniques a priority.

B. FOLLOW-ON RESEARCH

The dataset contains a large number of variables, but it contains only limited observations of certain variable types. These variables should have priority for additional experiments.

1. Night Conditions

Night conditions require more testing. The current night observations are not indicative of modern rifleman capabilities. The primary reason is the ambient light available during the period of testing. Under more favorable conditions, riflemen can—and are expected to—hit range targets at 250 meters, just 50 meters short of day-time conditions (FM 3-22.9, 2004). The one night of testing was overcast and without moonlight. Visibility was not conducive to night operations.

Visibility is a major factor in night operations, and future data would be most valuable if it included ambient light conditions. This information is not part of the current dataset.

2. Kneeling Posture at Short Range

Having only one posture on the short-range targets limits the current model. One or more additional postures for the short-range targets would

improve the model. Within the postures, Kneeling should have priority for further short-range testing. The next priority is the Prone posture. A model from three postures would be superior to the current model.

One note about gathering additional data for short-range targets: the Army does not have a standardized, automated short-range rifle facility. As said earlier, this study did not collect data for multiple postures due to restrictions on the range. Range Control of Fort Riley was willing to accept hasty coordination to make this study possible, but this should not be expected of other facilities. Future experiments should conduct deliberate planning far in advance to gain access to a Combat Pistol Qualification Range.

3.   Target Movement

Actual combatants rarely behave like static plastic targets. The study did not have access to a moving target range. Thus, target movement is not included as a factor for Probability of Hit. This is a critical missing component if one hopes to construct a truly realistic PH model. Follow-on research can be improved by adding the effects of target movement into current models.

One opportunity for gathering this type of data lies with the Engagement Skills Trainer (EST) 2000, discussed in Chapter I. The EST contains moving target scenarios for marksmanship training, and these tables offer an established, easily implemented method to measure how a target's movement affects a rifleman's Probability of Hit.

4.   Shooter Movement and Fatigue

In addition to the movement of the target, the shooter's movement requires measurement. One assumption of this model is that the rifleman remains stationary while shooting. This is a valid assumption for most scenarios, but nothing restricts a shooter from firing while moving. Shooter movement does have an effect on the bullets, but may create a more important effect—fatigue. The Soldiers rested prior to firing each table, and it was logical to assume the tables were not physically exhausting. This is not to say that fatigue would not

become a factor if they continued to fire for extended periods of time. Additional experiments, therefore, could duplicate the existing tables after prescribed levels of activity, perhaps 200 meters of sprinting, 3 kilometers of marching, carrying a casualty litter for 100 meters, or digging a fighting position for 5 minutes. These are all plausible activities a Soldier executes immediately prior to a shooting engagement. The test could use percentage of Heart Rate Reserve (HQDA FM 21-20, 1998) and activity duration as measurements of physical effort.

C.   SUMMARY

The rifleman is the tip of the spear in the Global War on Terror. While advance technologies aid in sensing and targeting threats, the country sill relies on the rifleman to pull those threats out of hiding. It was the rifleman, and not the precision guided-munitions, that brought Saddam Hussein to justice. In being the tip of the spear, riflemen must continue to improve their craft. If in doing so, our riflemen are so lethal that our enemies find it useless to combat them, the rifleman may ultimately create a method of preserving lives by convincing the enemy to avoid conflict.

The purpose of this study is to improve rifleman lethality. Thousands of United States servicemembers spend days if not weeks on rifle ranges each year to become the best rifleman possible. They do so because they know their lives depend on those skills. Those servicemembers' leaders and trainers continually look for better methods to train those in their charge. They march forward with the trust that they have the best equipment and training this nation can provide. We hope the analysis and models in this thesis help support the improvement of rifleman training, equipment, and tactics.

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APPENDIX A: MODEL #2 JMP-IN REGRESSION REPORT

The report below is from JMP-IN for Model #2 for a Mixed Stepwise Logistical Regression with α = 0.10 for both entering and leaving variables. The beginning model uses Target Range, Target Angle, Target Exposure Time and Shooter Posture to determine the shooter's Probability of Hit for the target. The Hosmer-Lemeshow Test *p*-value is 8.5%.

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	131.8254	10	263.6508	0.0001
Full	1824.5773			
Reduced	1956.4027			

RSquare (U)	0.0674	
Observations (or Sum Wgts)		2930

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	61	110.3015	220.603
Saturated	71	1714.2758	**Prob>ChiSq**
Fitted	10	1824.5773	<.0001

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-3.4796629	0.3933345	78.26	<.0001
MILS	-0.0817126	0.0261329	9.78	0.0018
(MILS-19.7365)*(MILS-19.7365)	-0.0005938	0.0001213	23.97	<.0001
TIME_EXP	-0.0466416	0.0240419	3.76	0.0524
(TIME_EXP-6.74676)*(TIME_EXP-6.74676)	0.04653913	0.0068778	45.79	<.0001
TGT_RANGE	0.00436881	0.0018143	5.80	0.0160
(TGT_RANGE-118.991)*(TGT_RANGE-118.991)	0.00004813	0.0000112	18.54	<.0001
POSTURE_ID	1.14165293	0.2085718	29.96	<.0001
(POSTURE_ID-2.60068)*(MILS-19.7365)	0.07810202	0.0174994	19.92	<.0001
(POSTURE_ID-2.60068)*(TGT_RANGE-118.991)	0.00296813	0.00084	12.49	0.0004
(TIME_EXP-6.74676)*(TGT_RANGE-118.991)	-0.0017342	0.0003731	21.60	<.0001

For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
MILS	1	1	9.7769586	0.0018
MILS*MILS	1	1	23.9687079	0.0000
TIME_EXP	1	1	3.76365455	0.0524
TIME_EXP*TIME_EXP	1	1	45.7866475	0.0000
TGT_RANGE	1	1	5.79841847	0.0160
TGT_RANGE*TGT_RANGE	1	1	18.5430509	0.0000
POSTURE_ID	1	1	29.9610485	0.0000
POSTURE_ID*MILS	1	1	19.9194325	0.0000
POSTURE_ID*TGT_RANGE	1	1	12.4859535	0.0004
TIME_EXP*TGT_RANGE	1	1	21.598094	0.0000

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APPENDIX B: MODEL #3 JMP-IN REGRESSION REPORT

The report below is from JMP-IN for Model #3 for a Mixed Stepwise Logistical Regression with α = 0.10 for both entering and leaving variables. An in-depth description of this model's variables are available in Chapter IV, Section B.1. This model's Hosmer-Lemeshow Test *p*-value is 19.7%.

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	427.5732	38	855.1463	<.0001
Full	1068.4078			
Reduced	1495.9809			

RSquare (U)   0.2858
Observations (or Sum Wgts)   2242

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare	
Lack Of Fit	1269	693.6427	1387.285	
Saturated	1307	374.7651		Prob>ChiSq
Fitted	38	1068.4078	0.0110	

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-7.3291748	8.6782518	0.71	0.3984
SOL.HT.M	11.2110147	4.9925877	5.04	0.0247
Equipment Weight	-0.0290865	0.049185	0.35	0.5543
(Equipment Weight-21.8686)*(Equipment Weight-21.8686)	-0.0040089	0.0007226	30.77	<.0001
EQUIP_WT_RATIO	2.29481259	4.2352385	0.29	0.5879
YEARS_OF_SERVICE	-0.0714946	0.0471364	2.30	0.1293
MILS	-0.4354926	0.0780598	31.12	<.0001
TIME_EXP	-0.2555361	0.069226	13.63	0.0002
TGT_RANGE	-0.0554288	0.0154795	12.82	0.0003
SPD_MPS	-0.4390262	0.138286	10.08	0.0015
TEMP_C	-0.1063935	0.0528021	4.06	0.0439
WIND_DFLX	-1.8166417	0.6666434	7.43	0.0064
WEAPON{M203-M16&M4}	-2.4371221	0.8102426	9.05	0.0026
WEAPON{M16-M4}	-7.9653883	1.6956174	22.07	<.0001
AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}	-6.0735592	1.2437158	23.85	<.0001
POSTURE{KNEELING-PRONE &STAND}	-0.4372988	0.2723778	2.58	0.1084
POSTURE{PRONE &STANDING-SUPPO	1.19053856	0.1667299	50.99	<.0001
POSTURE{PRONE -STANDING}	-2.3616992	0.2755784	73.44	<.0001
SING_MULTI[M]	0.35784726	0.0971715	13.56	0.0002
(M16-M4-0.71365)*(SOL.HT.M-1.77943)	-70.651314	17.039067	17.19	<.0001
(WEAPON{M203-M16&M4}+0.49866)*(Equipment Weight-21.8686)	-0.4686705	0.0821671	32.53	<.0001
(M16-M4-0.71365)*(EQUIP_WT_RATIO-0.27617)	-88.504139	14.136009	39.20	<.0001
(M16-M4-0.71365)*(YEARS_OF_SERVICE-3.50691)	-0.5634962	0.1273405	19.58	<.0001
(M203-M16&M4+0.49866)*(POSTURE{PRONE -STANDING}-0.02409)	-0.5157311	0.2307656	4.99	0.0254
(M203-M16&M4+0.49866)*(TGT_RANGE-108.227)	-0.0094936	0.003339	8.08	0.0045
(M16-M4-0.71365)*(TGT_RANGE-108.227)	-0.0135488	0.0059365	5.21	0.0225
(M16-M4-0.71365)*(SPD_MPS-3.6154)	2.08011813	0.3213207	41.91	<.0001
(AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}+0.80196)*(EQUIP_WT_RATIO-0.27617)	-15.72575	3.6135068	18.94	<.0001
(AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}+0.80196)*(MILS-23.7294)	-0.2726197	0.0671159	16.50	<.0001
(AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}+0.80196)*(TIME_EXP-6.38314)	0.14263793	0.0645893	4.88	0.0272
(SOL.HT.M-1.77943)*(POSTURE{KNEELING-PRONE &STANDING&FOXHOLE }+0.88046)	14.596977	5.9936669	5.93	0.0149
(Equipment Weight-21.8686)*(POSTURE{PRONE -STANDING}-0.02409)	-0.0423996	0.0115953	13.37	0.0003
(EQUIP_WT_RATIO-0.27617)*(TGT_RANGE-108.227)	0.02121072	0.0084405	6.32	0.0120
(EQUIP_WT_RATIO-0.27617)*(TEMP_C-5.04064)	-2.6110715	0.4211145	38.44	<.0001
(YEARS_OF_SERVICE-3.50691)*(POSTURE{KNEELING-PRONE&STANDING&FOXHOLE }+0.88046)	0.22741307	0.0906685	6.29	0.0121
(POSTURE{PRONE-STANDING}-0.02409)*(TIME_EXP-6.38314)	0.20382839	0.0553648	13.55	0.0002
(POSTURE{PRONE-STANDING}-0.02409)*(WIND_DFLX-0.25081)	0.94752142	0.4531221	4.37	0.0365
(MILS-23.7294)*(TGT_RANGE-108.227)	-0.0032452	0.0007088	20.96	<.0001
(WIND_DFLX-0.25081)*(SPD_MPS-3.6154)	0.57553756	0.2009002	8.21	0.0042

For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
SOL.HT.M	1	1	5.0424133	0.0247
Equipment Weight	1	1	0.34971724	0.5543
Equipment Weight*Equipment Weight	1	1	30.7746406	0.0000
EQUIP_WT_RATIO	1	1	0.29358828	0.5879
YEARS_OF_SERVICE	1	1	2.30055924	0.1293
MILS	1	1	31.124808	0.0000
TIME_EXP	1	1	13.6259358	0.0002
TGT_RANGE	1	1	12.8220945	0.0003
SPD_MPS	1	1	10.0791617	0.0015
TEMP_C	1	1	4.06001513	0.0439
WIND_DFLX	1	1	7.42593944	0.0064
WEAPON{M203 Grenade Launcher-M16A2/4 Rifle&M4 MWS }	1	1	9.04741327	0.0026
WEAPON{M16A2/4 Rifle-M4 MWS }	1	1	22.067757	0.0000
AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}	1	1	23.847577	0.0000
POSTURE{KNEELING-PRONE &STAND	1	1	2.57758698	0.1084
POSTURE{PRONE &STANDING-SUPPO	1	1	50.9870881	0.0000
POSTURE{PRONE -STANDING}	1	1	73.444431	0.0000
SING_MULTI	1	1	13.5617963	0.0002
WEAPON{M16A2/4 Rifle-M4 MWS }*SOL.HT.M	1	1	17.1928893	0.0000
WEAPON{M203 Grenade Launcher-M16A2/4 Rifle&M4 MWS }*Equipment Weight	1	1	32.5341681	0.0000
WEAPON{M16A2/4 Rifle-M4 MWS }*EQUIP_WT_RATIO	1	1	39.1988702	0.0000
WEAPON{M16A2/4 Rifle-M4 MWS }*YEARS_OF_SERVICE	1	1	19.5816362	0.0000
WEAPON{M203 Grenade Launcher-M16A2/4 Rifle&M4 MWS }*POSTURE{PRONE -STANDING}	1	1	4.99464395	0.0254
WEAPON{M203 Grenade Launcher-M16A2/4 Rifle&M4 MWS }*TGT_RANGE	1	1	8.08421275	0.0045
WEAPON{M16A2/4 Rifle-M4 MWS }*TGT_RANGE	1	1	5.20877768	0.0225
WEAPON{M16A2/4 Rifle-M4 MWS }*SPD_MPS	1	1	41.9081696	0.0000
AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}*EQUIP_WT_RATIO	1	1	18.9393456	0.0000
AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}*MILS	1	1	16.4992532	0.0000
AIM_DEVICE{OTHER-M68CCO&IRONSIGHT}*TIME_EXP	1	1	4.87695947	0.0272
SOL.HT.M*POSTURE{KNEELING-PRONE &STANDING&FOXHOLE }	1	1	5.93117371	0.0149
Equipment Weight*POSTURE{PRONE -STANDING}	1	1	13.3707977	0.0003
EQUIP_WT_RATIO*TGT_RANGE	1	1	6.31508723	0.0120
EQUIP_WT_RATIO*TEMP_C	1	1	38.4447509	0.0000
YEARS_OF_SERVICE*POSTURE{KNEELING-PRONE&STANDING&FOXHOLE }	1	1	6.29097036	0.0121
POSTURE{PRONE -STANDING}*TIME_EXP	1	1	13.5538411	0.0002
POSTURE{PRONE POSTUURE-STANDING}*WIND_DFLX	1	1	4.37267828	0.0365
MILS*TGT_RANGE	1	1	20.9632671	0.0000
WIND_DFLX*SPD_MPS	1	1	8.20704113	0.0042

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APPENDIX C: COMBAT VETERAN SURVEY RESPONSES

The questions and responses below were submitted by veterans of Operation Iraqi Freedom. They are the basis for several "conventional wisdom" remarks in the study regarding the effects of body armor and posture. The responses are generally unedited except for spelling and to clarify acronyms. Responses are grouped by question and annotated by responder (e.g. Response 2.1 is the answer to Question 2 from Subject 1.)

1.   SUBJECT DEMOGRAPHICS

Subject ID	Rank	Duty Position	Years of Service
1	Staff Sergeant	Battalion Master Gunner	16
2	Captain	Company Commander	12
3	Master Sergeant	Live Fire Operation NCOIC	22
4	Private First Class	Grenadier	1
5	Specialist	SAW Gunner	2
6	Sergeant	Team Leader	2.5
7	Private First Class	Grenadier	1
8	Staff Sergeant	Squad Leader	6
9	Private First Class	Grenadier	1
10	Private First Class	Mortarman	1.5
11	Staff Sergeant	Squad Leader	6
12	First Lieutenant	Platoon Leader	2
13	Sergeant	Team Leader	4
14	Captain	Company Trainer	18
15	Private First Class	Assistant Gunner	1
16	First Lieutenant	Platoon Leader	11
17	Major	Battalion Operations Officer	16

2.   QUESTIONS AND RESPONSES

Question 1: The conflicts of the IBA with rear SAPI plate and the PASGT Helmet are well documented, and the modified profile of the ACH was design to correct this. In your opinion, how does the current system of Kevlar armor equipment (helmets and body equipment) affect your skill of shooting a rifle?

1.1   "Most soldiers place the weapon on the meaty portion of the shoulder. The design of the IBA doesn't allow the Butt Stock to be placed in the shoulder pocket during Prone Fire. Kneeling and Standing Positions have shown no abnormal firing problems."

1.2   "I was a Company CDR w/ the 3d ACR in Iraq in both Ramadi and Fallujha. We had the IBA and the old style K pot. IBA w/ both plates in is bulky and heavy considering all the other stuff we carry. The new helmet seems much better but we did not have them. We wore the IBA and K pot 24x7 and only took it off when sleeping (a few hrs daily)."

1.3   "Because of the bulk of the equipment it is hard to get a good shoulder fire position. It's good for a quick fire or firing at a short distance. But good aim sight you must have 4 basic of Marksmanship. It can protect you from a round or fragments. "

1.4   "In my overall analysis, the ACH is an effective alternative to the previous Kevlar. In contrast, the ACH provides comfortable heads cushions and proper visibility. This furnishes a better environment for proper shooting, complimenting a natural head movement. However, the IBA still has some issues that cause discomfort while firing. The IBA tends to be ill-fitting, choking the neck with the throat protector, thus leading to uneasiness that hinder proper shooting."

1.6   "The Kevlar is still pushed up by the IBA, so it is hard to see."

1.7   "In the prone position, the IBA system makes shooting difficult."

1.8   "I felt the ACH worked well with the IBA in the prone."

1.9   "The only problem I encountered was shooting from the prone and keeping or finding a good pocket in my shoulder to fire from."

1.10   "I find that firing from the prone is still difficult with the existing system of Kevlar armor equipment. The rear SAPI plate prevents me from raising my head high enough to see an accurate sight picture without much strain and effort."

1.11   "My squads' shooting skills, it has not. Allowing us to move and shoot has not been a problem. Laying in the prone and firing can be a problem, but the only time we ever firing from the prone is zeroing/qualifying or when assaulting a bunker or trench at Fort Bragg."

1.12   "The current Kevlar system does not affect close quarters or short-rante shooting (inside of 200 meters). It is a problem when firing from the prone, zeroing, qualifying or long distance shots (outside of 250 meters)."

1.13   "From my experience, the IBA actually help improve the shooting by creating a better pocket for the buttstock. The ACHs only affect is that it loosens up very quickly."

1.15   "It's too bulky, it needs to be slimmed down."

1.17   "No issues. ACH doesn't conflict with IBA or shooting, provided troopers do the Live Fire Exercise training with the IBA and ACH."

Question 2: In a combat situation, how did having body armor affect a soldier's behavior?   Did he choose different firing postures, fighting positions, routes than he would if he did not have body armor? Did it make him more or less aggressive/confident in his ability to hit a target, and why?

2.1 "Soldiers chose to fire from the Kneeling and Standing positions more often due to the distance that they were off of the ground. The only time I saw soldiers in the prone was when they were on the side of a hill or mound. We chose to move in a more open area, and high speed avenues of approach, the bulk that we had prevented us from maneuvering through "tight" spaces, and over obstacles."

2.2 "After getting a few guys shot, we all saw how effective the IBA was and the K pots saved a few lives. The additional wt and bulk, however, tired the guys down quicker and forced more H_2O consumption. We got the IBA only a short time before deploying and didn't train wearing both plates. Suggest units wear / shoot / train with IBA and all equipment before deploying to get used to the bulk and added weight."

2.3   "Because he has the IBA or its rep's I feel the soldiers is more apt to think he cannot be hurt. But he also knows that he's not Superman. Looking at some of the firing positions I have seen soldiers use. Like standing or kneeing in the open area or standing in the middle of the road, when there is a vehicle that he could get cover from."

2.4   "In a combat situation, the body armor seems to build soldier's confidence. Enabling soldiers to perform their military duties with more aggressiveness to hit their targets. Also, giving opportunities to take routes and firing positions that normally would not be taken without the body armor."

2.5   "He might have gotten tired of constantly wearing the body armor. He chooses firing postures that were appropriate. I don't thing the IBA makes a Soldier more or less aggressive."

2.6   "The IBA makes you feel a little more sure of yourself."

2.7   "Wearing the IBA brought confidence and assurance that wouldn't be thought of or felt if a Soldier would not be wearing it."

2.8   "My firing positions didn't change at all, but having the additional armor did make me feel more confident."

2.9   "For the most part, confidence was up, but I don't think it affected decision making."

2.10   "The body armor improved most Soldiers' confidence of safety. They were less likely to shoot from the prone without being instructed to do so. With the increased confidence also came more aggressiveness."

2.11   "It made Soldiers more confident. All shots were taken while moving, standing still or on a knee. Aggressiveness had more to do with the mission type—not the IBA. To tell you the truth, his ability to hit targets while firing a rifle was not so much affected. Pistol shooting would cause a problem because you can't roll your shoulders forward due to the design of the IBA."

2.12   "Body armor does not affect a Soldier's behavior or routes traveled. It does encourage non-prone firing positions. Kevlar body armor does increase a Soldier's aggressiveness and sense of being indestructible."

2.13   "No, Soldiers react on instinct, firing position changes because of the equipment."

2.15   "More confident."

2.16   "Prone positions are a little cumbersome. You tend to lean off to the non-firing side."

2.17   "Shooting positions: Obviously there are steady-hold issues with IBA. IBA and ACH had no impact on my actions under fire—you're just as scared with or without it."

Question 3: Were there situations when not wearing body armor (both helmet and IBA) was preferred to wearing it? Were there instances when a soldier would drop his body armor while in a combat situation, such as to run down a suspect?

3.1 "Soldiers NEVER dropped their IBA. On a few occasions soldiers took off the ACH to facilitate seeing through a window without being seen."

3.2 "Always wore helmet and IBA. It's bulky and heavy but saves lives. Had three guys lose legs, but all shots to the body were protected by the body armor. We had one soldier hit in the chest close range w/ 7.62mm, it left an impression of his dog tag on his chest and knocked him down, but did not cause serious injury."

3.3 "No, I think you can wear it when chancing a suspect. You will get hot and tried in it, but I feel a person can do his mission with it on. Now on the other hand, if I need to do a good shot, I wouldn't want to wear it because you cannot get a firm position with it on. (i.e....shoulder to butt stock)"

3.4 "Circumstances such as going to the port-a-john with body armor is not a favorite method amidst soldiers. Yet, the training provided before-hand with the body armor, makes running with the equipment bearable, appropriately letting Soldiers run down a suspect with minimal hesitation."

3.6 "Always wore body armor."

3.7 "There was never a time, in a combat situation, that the IBA and/or helmet were not worn."

3.8 "While in a sniper position for extended times, it would be preferred to remove the IBA and ACH. As far as speed goes, yes, it does affect your mobility."

3.9 "The only place I would have wanted to drop the armor would be while in observations posts (OPs). No."

3.10 "There were times when Soldiers were posted inside buildings for OPs. The long hours of concealment caused many Soldiers to remove the body armor for comfort. In direct combat situations, no one removed their body armor."

3.11 "The only time you would not be wearing your body armor was in a safe zone. There were not instances when one of my Soldiers would drop his IBA while in a combat situation to run down a suspect."

3.12 "Paratroopers never shed their body armor in a combat situation. The only situations when body armor came off was within the Green Zone, within the Forward Operation Bases (FOBs) and inside or within 5 meters of a building that was inside a secured area (i.e. fire base)."

3.13 "No, there was no need."

3.17 " No. Snipers preferred to drop all for accuracy. Additionally, they cannot stalk in IBA and ACH. No time to drop equipment in contact. Again, you do what you always do (as you've trained)."

Question 4: Did the body armor (both helmet and IBA) affect the use of the M16A4 or M4 MWS and its sub-systems (M68 CCO, PEQ-2A, etc)? Were there retraining issues involved with operating with body armor, such as modifying the shoulder stock position?

4.1 "We went with what we had and trained our soldiers to pay closer attention to butt stock placement. "

4.2 "Soldiers carried their weapons at the low ready more often on patrols b/c the bulk. Larger framed guys had an easier time than shorter soldiers. M68, PEQ- 2/ 4 and Nods not affected directly, but sight pictures may be different with the armor on vs. off."

4.3 "Yes, it does."

4.4 "There is not a significant concern with the body armor affecting the use of the M16A4 or M4 MWS and its sub-systems to be noted."

4.6 "Yes, the M4 slides off at the soldier."

4.7 "Only in the prone position would the body armor would affect the quality of the shot."

4.8 "No. One improvement would be to have more MOLLE-type strapping, especially in the middle and higher in front. It would be far superior if it could be put on and removed "bib" style (Velcro and straps on the shoulders and sides)".

4.9 "There was little to no interference."

4.10 "No. The only conflict was firing the rifle from the prone, as previously mentioned."

4.11 "Effects were not noticed while firing at enemy targets. There are some movement issues due to the design. The entire weight rests on your shoulders. The way you close it with Velcro in the front isn't the best idea but we're not going to see any changes in our kits due to my comments. If we want to develop a better system, lets grab some of us guys that operate in it and let them from a better system."

4.12 "The subsystems on the M4 were not affected by the body armor. Reference answer #1 also. The shoulder stock position is changed to the pectoral muscle area instead of the 'armpit'. This is done because the IBA edge cuts through the 'armpit' stock-well position."

4.13 "No retraining involved."

4.14 "The sitting firing posture is one that should be trained. Several NCOs said that it is possible to move in and out of this position as quickly as the prone, and it is more accurate when trained. I thought it was [non-sense] until they showed me. The kneeling posture is quicker to get out of, but as far as accuracy, the sitting position is better."

4.17 "Yes. I used to leave the M4 butt fully extended. No with IBA, I leave it in the second locking position. Again, how we trained was how we executed."

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APPENDIX D: CHI-SQUARE TEST

If testing against known standard, p_i^0,

where i corresponds to an element in the set of target distances, I,
with $I = \{50, 100, 150, 200, 250, 300 \text{ meters}\}$.

Under H_0, $\hat{p}$ is asymptotically distributed as a Normal $\left(p_i^0, \dfrac{p_i^0(1-p_i^0)}{n_i} \right)$

So, $\dfrac{\hat{p}_i - p_i^0}{\sqrt{\dfrac{p_i^0(1-p_i^0)}{n_i}}} \sim Normal(0,1)$

and $\chi_i = \left(\dfrac{\hat{p}_i - p_i^0}{\sqrt{\dfrac{p_i^0(1-p_i^0)}{n_i}}} \right)^2 \sim \chi_{1df}^2$

If $\chi_i \overset{i.i.d}{\sim} \chi_{1df}^2$, then $\sum_I \chi_i \sim \chi_{6df}^2$

Reject H_0 if $\sum_I \chi_i > \chi_{6df}^2(\alpha)$

If testing two homogeneous populations are equal, $\hat{p}_i^1 \cong \hat{p}_i^2$:
where i corresponds to an element in the set of target distances, I,
with $I = \{50, 100, 150, 200, 250, 300 \text{ meters}\}$.

Under H_0 $\dfrac{\hat{p}_i^1 - \hat{p}_i^2}{\sqrt{\dfrac{p_i^1(1-p_i^1)}{n_i} + \dfrac{p_i^2(1-p_i^2)}{n_2}}} \sim Normal(0,1)$

and $\chi_i = \left(\dfrac{\hat{p}_i^1 - \hat{p}_i^2}{\sqrt{\dfrac{p_i^1(1-p_i^1)}{n_i} + \dfrac{p_i^2(1-p_i^2)}{n_2}}} \right)^2 \sim \chi_{1df}^2$

If $\chi_i \overset{i.i.d}{\sim} \chi_{1df}^2$, then $\sum_I \chi_i \sim \chi_{6df}^2$

Reject H_0 if $\sum_I \chi_i > \chi_{6df}^2(\alpha)$

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