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# PAYING FOR WEIGHT IN BLOOD: AN ANALYSIS OF WEIGHT AND PROTECTION LEVEL OF A COMBAT LOAD DURING TACTICAL OPERATIONS

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# NAVAL POSTGRADUATE SCHOOL

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# THESIS

**PAYING FOR WEIGHT IN BLOOD: AN ANALYSIS OF WEIGHT AND PROTECTION LEVEL OF A COMBAT LOAD DURING TACTICAL OPERATIONS**

by

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June 2019

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To gain, retain, or increase an advantage over enemy forces, military leaders have emphasized the importance of providing the latest and greatest technology to the warfighter. A common—possibly unintended but accepted—consequence of this effort is an increased combat load. Unfortunately, there appears to be a profound misunderstanding of how an excessive external load reduces the lethality and survivability of warfighters, as seen by the significant increase in combat loads over the past two decades. Agent-based simulation is used to investigate the effects of combat load weight. This thesis analyzes a scenario in which a 13-Marine rifle squad rushes across 100 meters of desert terrain while engaging four enemy fighters in defensive positions. Data obtained from nearly one million simulated firefights reveals that the reduction in speed from carrying an extra 15 pounds of gear—the difference between the Marine Corps' fighting and assault loads—results in an additional casualty for the squad. Also, if a Marine is moving such that they are at least twice as hard to hit as a stationary target, the expected number of squad casualties is reduced from 8.9 to 3.5. It is recommended that a holistic approach to weight reduction be implemented in order to reduce the fighting load to under 50 pounds and the assault load to under 75 pounds. Military leaders must balance the risk and reward of each piece of gear assigned to the combat load; the difference could be life or death.

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# PAYING FOR WEIGHT IN BLOOD: AN ANALYSIS OF WEIGHT AND PROTECTION LEVEL OF A COMBAT LOAD DURING TACTICAL OPERATIONS

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Submitted in partial fulfillment of the
requirements for the degree of

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# ABSTRACT

To gain, retain, or increase an advantage over enemy forces, military leaders have emphasized the importance of providing the latest and greatest technology to the warfighter. A common—possibly unintended but accepted—consequence of this effort is an increased combat load. Unfortunately, there appears to be a profound misunderstanding of how an excessive external load reduces the lethality and survivability of warfighters, as seen by the significant increase in combat loads over the past two decades. Agent-based simulation is used to investigate the effects of combat load weight. This thesis analyzes a scenario in which a 13-Marine rifle squad rushes across 100 meters of desert terrain while engaging four enemy fighters in defensive positions. Data obtained from nearly one million simulated firefights reveals that the reduction in speed from carrying an extra 15 pounds of gear—the difference between the Marine Corps' fighting and assault loads—results in an additional casualty for the squad. Also, if a Marine is moving such that they are at least twice as hard to hit as a stationary target, the expected number of squad casualties is reduced from 8.9 to 3.5. It is recommended that a holistic approach to weight reduction be implemented in order to reduce the fighting load to under 50 pounds and the assault load to under 75 pounds. Military leaders must balance the risk and reward of each piece of gear assigned to the combat load; the difference could be life or death.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ABS | Agent-Based Simulation |
| AMSAA | Army Material Systems Analysis Activity |
| AO | Area of Operations |
| APEC | All-Purpose Environmental Clothing |
| CCLTF | Close Combat Lethality Task Force |
| CFT | Combat Fitness Test |
| CNAS | Center for a New American Security |
| COMBAT XXI | Combined Arms Analysis Tool for the 21st Century |
| DN | Department of the Navy |
| DoD | Department of Defense |
| DOE | Design of Experiment |
| DTM | Directive-Type Memorandum |
| ESAPI | Enhanced Small Arms Protective Insert |
| E-Tool | Entrenching Tool |
| GAO | Government Accountability Office |
| GCE | Ground Combat Element |
| IAR | Infantry Automatic Rifle |
| IFAK | Individual First Aid Kit |
| IQR | Interquartile Range |
| IWARS | Infantry Warrior Simulation |
| KIA | Killed in Action |
| MANA | Map Aware Non-Uniform Automata |
| MANA-V | Map Aware Non-Uniform Automata – Version 5 |
| MCCDC | Marine Corps Combat Development Command |
| MCCU | Marine Corps Combat Utility |
| MCDP | Marine Corps Doctrinal Publication |
| MCS | Military Clean Skin |
| MOC | Marine Corps Operating Concept |
| MOS | Military Occupational Specialty |
| MRE | Meal, Ready-to-Eat |

| | |
|---|---|
| NCO | Non-Commissioned Officer |
| NIJ | National Institute of Justice |
| NOLH | Nearly Orthogonal Latin Hypercube |
| NVG | Night Vision Goggles |
| PPE | Personal Protective Equipment |
| RCO | Rifle Combat Optic |
| SA | Situational Awareness |
| SAPI | Small Arms Protective Insert |
| SURVIAC | Survivability/Vulnerability Information Analysis Center |
| T&R | Training and Readiness |
| USMC | United States Marine Corps |

# EXECUTIVE SUMMARY

The United States Marine Corps must "win our nation's battles swiftly and aggressively in times of crisis" (United States Marine Corps 2018). Essential to that mission is maneuver warfare. Since speed is vital to the execution of maneuver warfare, a conscious effort must be made to ensure every pound a Marine carries is essential for mission accomplishment. Currently, the Infantry Training and Readiness (T&R) Manual states that a fighting load is 49 to 60 pounds and an assault load is 63 to 77 pounds, neither of which account for the weapon system or additional Military Occupational Specialty (MOS)-specific equipment (Department of the Navy [DN] 2016). Unfortunately, recent history has shown that these standard loads are frequently exceeded by exorbitant amounts. In Iraq and Afghanistan some loads approached 160 pounds, double the standard assault load, depending on the individual's billet within the squad, with an average load carried of 117 pounds (Government Accountability Office [GAO] 2017). This weight, a portion of which provides ballistic protection, increases a Marine's susceptibility by reducing their ability to move quickly on the battlefield. The lack of mobility can mean the difference between life and death.

Previous studies have shown that increasing load decreases physical performance. An Australian study concluded that there was a 1.5 percent performance decrement for every kilogram (2.2 pounds) of external load added, which can compromise survivability and may affect the outcome of a battle (Peoples et al. 2010). Another study had 19 Australian Defence Force soldiers execute a fire and movement exercise of 16 six-meter bounds with five different external loads ranging from 21 to 66 pounds (Billing et al. 2015). The researchers found that the amount of time a soldier was exposed to enemy fire increased linearly as a function of external load and peak velocity decreased with increasing load (Billing et al. 2015). These conclusions are not trivial, as anyone who has carried a pack on their back can tell, but the tradeoff between weight and protection needs to be examined, as well as the point where weight affects casualties and mission success.

When prescribing a combat load, military leaders at all levels struggle to determine the ideal balance between assets to carry and the burden of their weight. Each item chosen serves a purpose, all of which are intended to improve a Marine's chances of survival and support mission accomplishment. To assist commanders' understanding of how the combat load can both enhance and diminish the effectiveness and survivability of the warfighter, agent-based simulation (ABS) was used to model a Marine rifle squad becoming engaged with a fireteam-sized element from 100 meters carrying various loads. Leveraging efficient design of experiments, parallel computing, and data analysis of 885,000 simulated firefights, the effects of weight carried into battle are quantified in terms of casualties and probability of mission success.

Commanders need to ensure all gear required for the combat load are truly mission-essential and none of the items were added to reduce the commander's aversion to risk. Gear added for this purpose only shifts the risk from the commander to the warfighter; it does not eliminate the risk. Grasping a better understanding of the human element of war will assist commanders' decision making regarding the appropriate combat load given their specific area of operations (AO). The primary findings from the simulated firefights of the thesis research are as follows:

- If a combat load is at least 43 pounds (fighting load without ballistic plates), adding just 15 pounds of gear increases the amount of time each Marine is exposed to enemy fire enough to result in an additional casualty per 13-Marine squad.

- The optimal load configuration, in terms of mission success, is achieved using the lightest standard load with the greatest level of protection for the enemy threat. This common-sense conclusion supports the current policy of allowing commanders in the field to determine the appropriate personal protective equipment (PPE) configuration based on the operational environment.

- When the weight carried is increased, the number of expected casualties increases *regardless of ballistic protection level*.

- Speed matters more for higher quality enemy marksmen. Skilled enemy sharpshooters only need the opportunity to fire and hit a target. Therefore, the increase in exposure time caused by a decrease in speed from a heavier combat load has a more drastic effect on the expected number of Marine casualties.
- A squad of Marines moving such that they are individually at least twice as hard to hit as a stationary target decreases the expected number of squad casualties by about 5.4 (from 8.9 to 3.5). Making the combat load light enough for Marines to maneuver at a speed that makes them twice as difficult to hit is one way to achieve this advantage.

**Focused Future Work**

In order to provide more insight and greater fidelity of the results, future work on the effects of combat load can focus on three areas. First, perform field experiments to compare with the simulation results. Specifically, the T&R standard fighting load, T&R standard assault load, and GAO report 117-pound average combat load should be examined in order to understand the true impact of weight carried on Marines (speed, fatigue, probability of being hit, etc.). Second, modify the model to simulate live fire testing done in the summer of 2018 conducted by The Marine Expeditionary Rifle Squad Team at Marine Corps Systems Command. This team looked at the probability of hitting moving targets at various speeds from distances of 100–300 meters. Third, use a high-resolution simulation model, such as the Combined Arms Analysis Tool for the 21st Century (COMBAT XXI) or Infantry Warrior Simulation (IWARS), to explore similar experiments with greater fidelity.

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I owe a debt of gratitude to Mary McDonald, without whom I would still be refining my thesis model. When it seemed as if progress on my thesis was doomed to stall, she devoted substantial time to modifying the model and running experiments to ensure it was working properly. Her simulation and statistical expertise transformed my conceptual idea into a data-driven, tangible model that combines the results from human-subject research with operational context to provide insights on the effects of combat load during a firefight.

Last but not least, I would like to thank my mom. Her steadfast support in everything I choose to pursue in my life has given me the strength to attack any challenge I am faced with. She always gave me perspective when I needed it, usually to my vexation, reminding me that life is 10 percent what happens to you and 90 percent how you react to it.

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# THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made within the time available to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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# I. INTRODUCTION

> The ability of Marine infantry to close with the enemy in every type of terrain and environment is an asymmetric advantage. This places a premium on the GCE's ability to conduct sustained, foot-mobile operations while bearing mission-essential equipment and personal protective gear.
>
> — *The Marine Corps Operating Concept: How an Expeditionary Force Operates in the 21st Century*

## A. BACKGROUND AND MOTIVATION

For thousands of years, people have met on the battlefield to fight for land, an ideology, and everything in between. How much to carry into combat has always been the subject of great debate and has ultimately been determined by commanders. From the Roman Legion to American forces during World War II, the weight of a combat load has varied from 33 pounds to over 80 (Marshall 1980). During the modern wars in Iraq and Afghanistan, loads approached 160 pounds depending on the individual's billet within the squad (GAO 2017). Recent advancements in technology have resulted in numerous strategic, operational, and tactical advantages over our enemies, increasing lethality and providing greater protection to service members. However, these capabilities also come at great cost: the cost of increasing the warfighter's load.

Studies have shown that increasing load decreases physical performance. A study completed by the University of Wollongong in Australia concluded that there was a 1.5 percent performance decrement for every kilogram (2.2 pounds) of external load added, which can compromise survivability and may affect the outcome of a battle (Peoples et al. 2010). This study examined weights up to just over 64 pounds, but a survey of infantry Marines found the average weight carried on a dismounted patrol was 96 pounds, which would result in an even greater decrement in performance (Jaworski et al. 2015). This conclusion is not trivial, as anyone who has worn a flak and Kevlar or carried a pack on their back can tell. What needs to be examined is the tradeoff between weight and protection, and at what point this affects the number of casualties and mission success.

The mission of the United States Marine Corps is to “win our nation’s battles swiftly and aggressively in times of crisis” (United States Marine Corps 2018). Essential to that mission is maneuver warfare. This requires seizing the initiative through the generation of a faster operating tempo relative to our enemy, which allows us to dictate the terms of action (Department of the Navy [DN] 1997). Tempo is created through speed over time and “speed is necessary in order to concentrate superior strength at the decisive time and place” (DN 1997). Since speed is vital to the execution of maneuver warfare, a conscious effort must be made to ensure every pound a Marine carries is essential for mission accomplishment. Currently, the Infantry Training and Readiness (T&R) Manual states that a fighting load is 49 to 60 pounds and an assault load is 63 to 77 pounds, neither of which include the weapon system or additional Military Occupational Specialty (MOS)-specific equipment, both of which are required during the conduct of basic infantry tasks (Department of the Navy [DN] 2016). This additional load—a portion of which decreases the Marine’s vulnerability to enemy fire by providing ballistic protection—increases the time required to complete combat movements, which translates to increased exposure time to enemy fire, in turn increasing a Marine’s susceptibility.

Marines welcome challenges head-on, with an “improvise, adapt, and overcome” mindset. As effective as this mindset is in unlocking the true potential of each Marine, pushing them beyond their self-set mental limits, this benefit has a ceiling. Marine leaders must truly understand and respect the physical capabilities and limitations of human beings, no matter how hard it may be to admit as “the few, the proud.” Over 65 years ago, S.L.A. Marshall warned that if the combat load was not reduced, we would be limiting the human potential we strive so hard to exploit (Marshall 1980).

This thesis uses agent-based simulation (ABS) to model a Marine rifle squad becoming engaged with a fireteam-sized element from 100 meters, subsequently closing with and destroying the enemy. Conclusions from the model’s outputs will support commanders’ understanding of how combat load can both enhance and diminish the effectiveness and survivability of the warfighter. This will, in turn, assist commanders’ decision making regarding the appropriate load given their specific area of operations (AO).

## B. SCOPE

As long as warfare is a part of this world, the load carried into battle by America's men and women will either contribute to their success or influence their failure. A delicate balance must be struck between assets to carry and the burden of their weight, which determine an individual's lethality, protection, and mobility. This thesis explores the effects of external load on casualties and mission success. Specifically, the results of this model will identify, if it exists, a critical point in static load above which the costs are disproportionally larger than its benefits.

## C. PROBLEM STATEMENT

Although there have been numerous studies proving the detrimental effects of external load on the performance of a range of physical tasks, there exists a significant gap in research determining the point at which combat survivability is compromised. This lack of scientific data and exploration has contributed to the steady increase in loads carried by Marines (Bachkosky et al. 2007). Crushing the warfighter under exorbitant weight is antithetical to the Marine Corps' doctrinal foundation of maneuver warfare.

The Commandant of the Marine Corps published the 2016 Marine Corps Operating Concept (MOC), which identified the critical task of enhancing the warfighter's ability to close with and destroy the enemy by enabling the infantry to maneuver more rapidly throughout the battlespace. Motivated by this critical task, this thesis seeks to answer the following two questions:

1. What is the effect of increasing external load, due to additional personal protective equipment (PPE) and mission-essential gear, on casualties and probability of mission success?

2. Is there a critical point in static load and/or percent body weight which should not be exceeded?

## D. METHODOLOGY

This thesis uses ABS to model the effects of increasing the warfighter's load during the conduct of a squad-level mission. Through an extensive literature review and conversations with subject matter experts in the Army and the Marines, significant model input factors were determined. The following research process was implemented to answer the thesis problem statement:

1. Collect data from relevant previous studies and government agencies to determine model inputs.

2. Develop and program a Map Aware Non-Uniform Automata – Version 5 (MANA-V) squad engagement scenario.

3. Apply design of experiments (DOE) techniques to efficiently explore factors.

4. Run simulations and analyze output.

## E. THESIS ORGANIZATION

Chapter II provides the reader with additional detail on the history of the problem, previous research leveraged in this thesis, and a description of the combat loads carried by Marines today. Chapter III presents an overview of general modeling and simulation techniques and terminology, as well as details of the thesis scenario implemented in MANA-V. Chapter IV steps through the implementation of the DOE and each experiment conducted. Chapter V discusses data collection and analysis. Chapter VI details thesis conclusions, avenues for improvement, and recommendations for future research.

# II. HISTORY OF THE PROBLEM

## A. WHAT THE PAST CAN TEACH US

Everyone knows that history has a tendency to repeat itself similar to how an object in motion tends to stay in motion unless acted upon by another force—we must learn and implement changes to avoid reliving past mistakes. Although tactics and technology have changed throughout the centuries, historical battles indicate a repetitive tendency for leadership to overburden soldiers with equipment they deem necessary and essential for their subordinates to carry into battle. From Bunker Hill, to Waterloo, to World War II, armies across the globe have carried at least 55 pounds and frequently exceeded 70 pounds in combat (Marshall 1980). When required to shoulder these loads, there are two options a soldier has: attempt to carry the weight (case 1), or dump whatever items they deem unnecessary (case 2); historical battles are filled with examples of both.

An example of carrying the full weight (case 1) is the Normandy landings on D-Day. For the amphibious landing operation—Operation Neptune—soldiers had a combat load in excess of 80 pounds (Marshall 1980). This weight, even under the best circumstances, is a heavy load to carry, let alone on a beach with a steady rain of bullets and a persistent danger of mines, drowning, and mortars. After completing thorough research and countless interviews with survivors of the Omaha beach assault, S.L.A. Marshall concluded that "the weight and water—directly or indirectly—were the cause of the greater part of our losses at the beach" (1980). This is striking since more than 10,000 Allied soldiers—including at least 6,600 Americans—are estimated to have been either killed, wounded, or designated as missing in action during the conduct of the invasion (The White House 2014).

Another example, of case 1, from World War II is the Battle of Iwo Jima. In preparation for a potential invasion of mainland Japan, U.S. forces required the island of Iwo Jima, specifically its three airfields. American forces planned and executed an amphibious assault on the heavily fortified island on February 19, 1945. On the soft volcanic ash, laden Marines—some carrying over 100 pounds apiece—struggled to push up the inclined beach, with each sinking step zapping them of vital energy and momentum (Camp 2007). Exposed, Marines pushed forward towards their objective, descending in the sand with every step they took (Figure 1).

Figure 1. Iwo Jima Beach Landing. Adapted from Camp (2007).

The prepared defenses, continuous artillery fire, and exhausted Marines led to casualties on a massive scale. Only after 36 days of battle did the Marines defeat the estimated 18,000 entrenched Japanese forces on the island, resulting in the deaths of nearly 7,000 Marines and wounding of over 20,000 (The National WWII Museum 2018). Knowing how weight carried can affect one's level of fatigue and ability to swim, it is not difficult to connect the shouldered load to casualties, particularly during amphibious operations. The possibility of saving at least one life during the execution of either the Normandy or Iwo Jima landings by lightening the load indicates we can do better as military planners.

For individuals dumping items they find unnecessary (case 2), D-Day once again offers insight. Operation Overlord had two main aspects; one was the amphibious landings and the other was the airborne assault. During the airborne assault, some paratroopers who jumped into Normandy required assistance to embark the planes because they weighed as much as 325 pounds, which amounts to 145 pounds of gear for a 180 pound man (Warren 1956). For many of the men who were lucky enough to land safely, they quickly abandoned any equipment they deemed unnecessary to facilitate swift movement to their objectives, enabling them to leverage surprise over firepower (Marshall 1980). Due to their lightness of foot, innovative tactics, and exceptional execution, these airborne paratroopers achieved extraordinary success that is lauded to this day.

The airborne is not the only example where a light load empowered troops to be successful in combat. Over two thousand years ago, the Roman legion, which drove the expansion of the Roman empire to one of the largest in history, carried only 33 pounds in combat (Marshall 1980). Although the designated weight was only used when fighting—and it is an estimated number—it is clear that, in comparison to the previous examples given, this load is drastically lighter. The Romans knew the advantage of a light combat load centuries ago, and we would be wise to learn from them.

## B. PREVIOUS RESEARCH

In a military context, the gear and equipment that comprise the external load serve two basic purposes, either to protect the servicemember from harm or provide a mission-essential function, such as firepower or breaching. From a load-centric perspective, the external load contributes either to a warfighter's survivability (protection) or susceptibility (vulnerability). In the past ten years, there have been several studies that have explored the effects of external load on the performance of various tasks. For context, this research is partitioned into two groups, survivability and susceptibility, delineated by what the researchers' conclusions affected most.

### 1. Effect of Load on Survivability

In order to provide protection from enemy gunfire, the military uses a combination of soft and hard armor. The National Institute of Justice (NIJ) has specific body armor levels that determine the maximum level of protection provided; a summary of the basic levels is shown in Table 1. NIJ level II is only the vest (soft armor) without any ballistic plates. NIJ level III is the vest with four small arms protective insert (SAPI) plates, which cover part of the torso, back, and sides. NIJ level IV is similar to level III, but replaces the SAPI plates with enhanced SAPI (ESAPI) plates.

Table 1. NIJ Body Armor Levels. Source: NIJ (2008).

| Round Protection | NIJ Level II | NIJ Level III | NIJ Level IV |
|---|---|---|---|
| *9 mm / 0.357 Magnum* | X | X | X |
| *7.62 mm (M80)* | | X | X |
| *0.30 Armor Piercing (M2 AP)* | | | X |

Because they are designed to protect vital organs that, if damaged, would result in serious injury or death, the benefits of PPE outweigh the cost of shouldering its load in combat. During combat operations, PPE has saved countless lives and will always be an essential part of the external load. Also essential to the external load is the weapon. This item enables warfighters to kill the enemy, removing his or her ability to injure or kill friendly forces. Both PPE and the individual's weapon system contribute to their survivability.

In combat, a Marine or Soldier must move quickly and fire precisely and accurately to give them the greatest chance of survival. Unfortunately, when overburdened, humans are unable to perform tasks at an optimal level, specifically due to the fatigue induced by the heavy load. In 2015, Jaworski et al. investigated how external load affects the performance of combat-related tasks, specifically a modified maneuver under fire exercise and shooting a simulated target at 50 meters (2015). Part of the Marine Corps' Combat Fitness Test (CFT), the maneuver under fire drill is a timed 300-yard shuttle run consisting of various combat-related tasks. Using 18 infantry Marines with combat deployment experience, first class CFT scores, and at least sharpshooter marksmanship designation, task completion time increased, shooting precision decreased, and overall shooting variability increased when the load approached 45 percent of the Marine's body weight (Jaworski et al. 2015). This study shows that there is a point at which the total load carried results in fatigue that affects a Marine's ability to both move quickly and engage the enemy for either lethal or suppressive purposes.

### 2. Effect of Load on Susceptibility

A servicemember is most susceptible to enemy fire when moving over exposed ground. During these periods, Marines use a technique called "buddy rushing." A single repetition of this technique consists of two parts: (1) one member of the two-person buddy pair in the prone position providing suppressive fire and (2) his or her partner sprinting towards their objective and then returning to the prone position in preparation for covering their buddy's rush. The pair alternate covering for each other and repeat the cycle until the objective has been reached. The execution of this tactic—sometimes referred to as fire and movement—was used as the basis for many of the studies researching the effects of external load.

One study had 19 Australian Defence Force soldiers execute a fire and movement exercise of 16 six-meter bounds with five different external loads ranging from 21 to 66 pounds (Billing et al. 2015). The researchers found that the amount of time a soldier was exposed to enemy fire increased linearly as a function of external load, the phase of movement most affected in performance was at the onset (rising from prone), and peak velocity decreased with increasing load (Billing et al. 2015). These findings are important for several reasons. Increasing exposure time results in more opportunities for the enemy to hit their target, thereby increasing the probability of a servicemember being wounded or killed. Next, the longer it takes to rise from the prone position, begin running, and reach top speed is a particularly vulnerable time, since the subject is either nearly stationary or moving slowly. A stationary or slow-moving target is much easier to hit than a fast-moving one, which also increases the probability of the enemy hitting their target. Lastly, if the maximum possible sprint speed of an individual decreases, the warfighter becomes an easier target to hit. A previous study had similar results timing a 30-meter sprint starting from the prone position with an external load of almost 48 pounds, finding the greatest performance decrement occurred during the first five meters of movement (Laing Treloar and Billing 2011).

The Australian Defence Force has studied this topic extensively, conducting multiple studies focusing on a range of input variables and physical tasks. One of the most important studies relative to this thesis was their analysis of the effects of a tiered body armor system on five tasks—fire and movement, obstacle avoidance, combat rush, vertical jump, and stand and reach (Peoples et al. 2010). With combat loads ranging from 42 to 64 pounds, the researchers concluded that increasing load:

- Reduced solider speed
- Increased task completion time
- Quickened the onset of fatigue during repetitive actions
- Negatively affected obstacle negotiation (Peoples et al. 2010).

The scientists understood the implications of their results and possible impacts they could have on a soldier's performance in combat. They also recognized an unexplored gap in their research and the studies conducted previously (which remains to this day). This gap was to "identify the point at which a reduction in physical mobility starts to compromise personal survivability on the battlefield" (Peoples et al. 2010). Similarly, the Center for a New American Security (CNAS), a defense and national security think tank, concluded that studies on load's effect on soldier movement speed fail to address its impact on operational effectiveness, such as exposure to enemy fire (Fish and Scharre 2018). The primary goal of this thesis is to fill that gap and identify, if it exists, a critical point for combat load which, if exceeded, results in a disproportionate increase in casualties.

## C. WHEN WILL WE LEARN?

Based on sustainment and operational requirements, the Marine Corps uses four standard load conditions in the execution of combat operations. These loads, in order of increasing sustainment duration, are the fighting load, assault load, approach march load, and sustainment load (DN 2016). Each load specification is intended to minimize weight to reduce its damage to combat effectiveness and may be altered by the commander. This thesis uses the two lightest loads, intended for short term combat operations, which are defined as the following:

- Fighting Load: "items of clothing, equipment, weapons, and ammunition that are carried by, and essential to, the effectiveness of the combat Marine and the accomplishment of the immediate mission" (DN 2016).
- Assault Load: "load that is needed during the actual conduct of the assault…includes minimal equipment beyond water and ammunition" (DN 2016).

The assault load includes everything from the fighting load, with the addition of three Meals, Ready-to-Eat (MREs), waterproof parka and trouser set, an entrenching tool (E-Tool), and the assault pack. These loads reference billet-specific equipment, also known as job-specific equipment, which can vary greatly between members of a squad. How much this difference affects weight is discussed later in this section. Figure 2 provides a visualization of most of the items required for both loads. Itemized tables for the standard fighting and assault loads can be seen in Appendix A. These tables use the term SL-3, which refers to a set of additional items that are part of a larger system (e.g., weapons cleaning gear is an SL-3 item for a rifle).

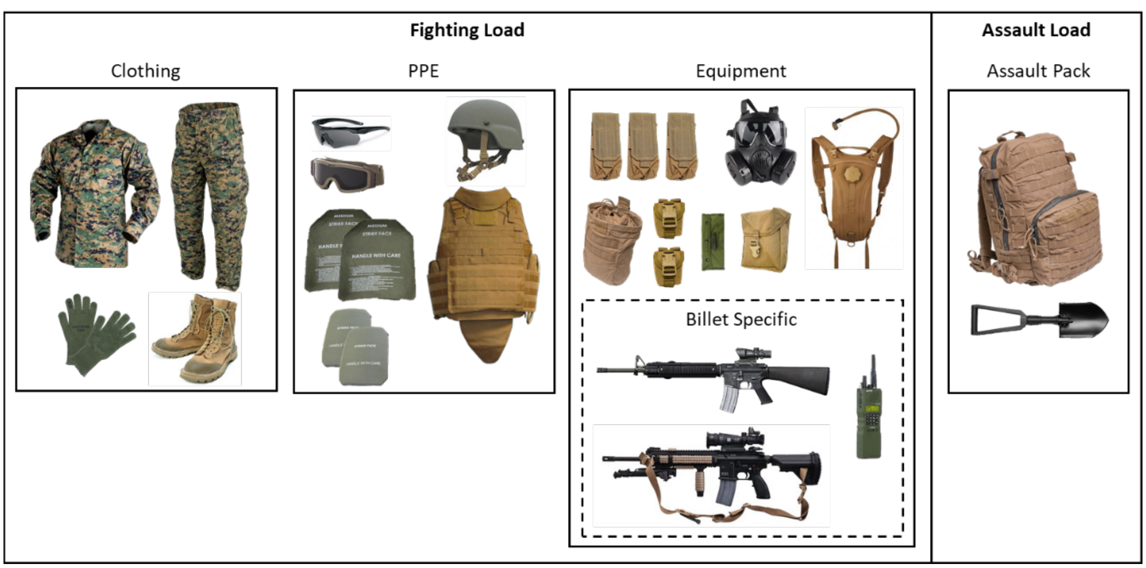


Figure 2. Marine Combat Loads. Adapted from Jilson (2016).

### 1. Fighting Load

The fighting load can be broken down into four basic groups: clothing, PPE, equipment, and billet-specific equipment (Table 2). This load can vary significantly based on a Marine's MOS and billet within the squad. For example, if a Marine is an automatic rifleman (described in detail later), they are required to carry the assault pack and 22 magazines. On the other hand, a rifleman—assigned either an M4 carbine or M16A4 rifle—requires only seven magazines and does not carry the assault pack.

Table 2. Fighting Load. Adapted from DN (2016).

| **Fighting Load** | | | |
|---|---|---|---|
| *Item* | *Quantity* | *Item* | *Quantity* |
| Clothing | | Equipment | |
| *MCCU, Blouse and Trouser* | *1* | *M50 Mask w/ Carrier* | *1* |
| *Uniform, Utility, Belt* | *1* | *Pouches (1-dump, 3-magazine, 2 grenade)* | *1/3/2* |
| *Gloves* | *1* | *IFAK - A1 First Aid Kit* | *1* |
| *T-Shirt, Green* | *1* | *AN/PVS-14 w/Elbow/Rhino Mount* | *1* |
| *Undershorts* | *1* | *Hydration System, CamelBak (Full)* | *1* |
| *Marine Corps Combat Boots w/ Laces* | *1* | *Weapons Cleaning Gear* | *1* |
| *Socks* | *1* | Billet-Specific Equipment | |
| *Watch, Wrist* | *1* | *Personal Weapon (M4, M16A4, or M27 IAR)* | *1* |
| *Card, ID* | *1* | *Assault Pack (M27 IAR)* | *1* |
| *Tags, ID* | *1* | *Magazines (M4/M16A4, M27 IAR)* | *7/22* |
| PPE | | *Combat Assault Sling* | *1* |
| *Ballistic Eye Protection* | *1* | *RCO* | *1* |
| *Helmet w/ Cover, Band, and NVG Base Plate* | *1* | *PEQ-15/16* | *1* |
| *Plate Carrier (soft armor)* | *1* | *Radio* | *1* |
| *SAPI Plates (front, back, and 2x side)* | *1* | *M203/M32 (if assigned)* | *1* |

### 2. Assault Load

As previously stated, the assault load requires everything from the fighting load, plus four items (Table 3). This load is used for combat operations that require sustainment beyond what the fighting load provides, but not for extended periods of combat. The assault load includes three MREs for sustenance, all-purpose environmental clothing (APEC) for adverse weather conditions, an E-Tool to dig fighting positions, and the assault pack to carry these items.

Table 3. Assault Load. Adapted from DN (2016).

| Assault Load | |
|---|---|
| *Item* | *Quantity* |
| ***Fighting Load*** | *1* |
| *Assault Pack* | *1* |
| *MRE* | *3* |
| *Parka and Trouser, APEC* | *1* |
| *Tool, Entrenching w/ Case (E-Tool)* | *1* |

### 3. Actual Load

Based on data collected from the wars in Iraq and Afghanistan, these standard loads have proven to be unrealistic in combat operations. The assault load is used more frequently than the fighting load, since Marines almost always carry their assault pack with extra gear. In 2007, Marine Corps Combat Development Command (MCCDC) estimated that the average rifleman's actual load was 97 pounds (Bachkosky et al. 2007). However, even after accounting for a rifleman's weapon and SL-3—assuming no additional billet-specific equipment—this load should weigh no more than 89 pounds when calculating the weight using the infantry T&R assault load (Appendix B). More recently, the GAO found that the typical load for Marines was between 90 and 159 pounds, depending on squad billet, with an average load of 117 pounds—exceeding the standard by 28 pounds (GAO 2017). This is not only a Marine Corps problem, it is a Department of Defense (DoD) problem; the report also stated that the Army had an average ground combat load of 119 pounds (GAO 2017).

Referencing the standard loads, these extra pounds appear to be attributable to mission-essential gear or risk-mitigation weight. Mission-essential gear is an umbrella term used for items leadership designates as required to execute the mission. Risk-mitigation weight encompasses all items that are added to the combat load that are the "just in case" solutions to "what if" scenarios that commanders worry about during operational planning. These items are the consequence of leadership not willing to risk his or her Marine(s) not having what they might need on the battlefield. This can be attributed to the risk-averse culture that is prevalent throughout the military, for good reason—"the resources [leaders] will expend in war are human lives" (DN 1997).

Unfortunately, leaders appear to profoundly misunderstand how an excessive external load reduces the combat effectiveness and survivability of warfighters. If they did, this issue would not be as prevalent as it has been for centuries, and the weight carried would not have reached the level it has within the last two decades. New technologies, like weapons systems and drones, have provided warfighters with increased lethality and situational awareness that give them offensive and defensive advantages over enemy forces, but most have also significantly increased the individual combat load. These new capabilities need to be delicately balanced with human limits. Unlike many problems within the DoD, this is not one that can be solved with training and conditioning. Instead, it requires commanders to carefully balance the risk, reward, and consequences of each piece of gear added to a combat load, with an understanding that every added ounce further progresses the total weight towards, or in excess of, human limitations. This thesis seeks to determine the critical point at which the benefits of additional load are outweighed by the cost—casualties in war.

# III. THE MODEL

This chapter introduces the reader to modeling, simulation, and the thesis model. Chapter III.A provides a brief overview of modeling, simulation, and agent-based simulation. Chapter III.B describes the software used to build the thesis model, called MANA-V. Chapter III.C details the thesis model scenario. Chapter III.D describes how the scenario was created in MANA and highlights the important assumptions made when developing the model. Chapters III.E and III.F outline the model agent characteristics for Blue (friendly) and Red (enemy) agents, detailing the research, data, and calculations used to determine those inputs. Chapter III.G discusses the limitations of the model used.

## A. MODELING AND SIMULATION

A model is defined as a "physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process" that is used over time (simulation) to collect data as a basis for decision making (Department of Defense [DoD] 1998). Basically, simulations are run to provide greater understanding of the factors (inputs) that affect the end state (outcome) of a system or process. Simulation brings a significant benefit in that it does not require broad, unrealistic assumptions that mathematical proofs often need for analytical tractability to calculate closed-form solutions—after a series of mathematical operations to arrive at "the answer." Due to improvements in technology and experimental methods, simulation has become the preferred method for the analysis of many complex, real-world problems (Lucas et al. 2015).

The DoD has used modeling and simulation for a wide range of tasks, from weapons system analysis to testing war plans. With the outcome determined by "possibilities and probabilities," war's inherent unpredictability make it especially challenging to gain insights (DN 1997). The human element in war is what makes it so uncertain. How human beings react based on training or natural instincts and how effectively they engage the enemy are just some of the aspects of a single engagement that can tip the scales in favor of either friendly or enemy forces. In order to simulate this type of behavior, agent-based models were developed.

Agent-based models use autonomous entities (agents), controlled by decision making algorithms, that can interact with other agents and their environment (McIntosh et al. 2007). Studying the results from thousands of simulation experiments can provide researchers with a greater understanding of what factors have the greatest influence on outcomes and help identify emergent behavior. The importance of the human element in engagements made ABS stand out as the method of choice for exploring the effects of external load on casualties.

## B. MAP AWARE NON-UNIFORM AUTOMATA (MANA-V)

This thesis used MANA-V, an agent-based modeling environment specifically designed to incorporate essential real-world aspects of combat, such as situational adaptation to an evolving battle (McIntosh et al. 2007). This agent-based, time-stepped, stochastic (randomly determined) model was created by the New Zealand Defence Technology Agency in 2000 (Lucas 2018). A driving force behind the creation of MANA was the desire to capture battlefield situational awareness (SA), terrain effects, communication between agents, and event-driven personality changes (McIntosh et al. 2007).

In MANA, a squad is a homogenous group of agents of any size that share properties that affect their behavior with respect to the environment and other friendly, enemy, or neutral agents. The squad builds its situational awareness via direct contact with other squads or information attained through communication links (McIntosh et al. 2007). The terrain, implemented using terrain and elevation maps, affects cover, concealment, mobility, and line-of-sight (Lucas 2018). Specified events (e.g., shot at) can trigger a distinct set of personality traits that differ from the squad's default state for a duration designated by the programmer. This enables agents to react based on the situation, similar to how humans adapt to their environment.

One of the many advantages of MANA is the simple graphical user interface that enables the programmer to build a model with relative ease. This interface also provides a visualization of each simulation run, designated by a random seed. A seed is a number that initializes a pseudorandom number generator, an algorithm that produces a sequence of numbers that have properties similar to random numbers (Tsakalaki 2019). These "random" numbers are used in MANA to determine state transitions as the simulation progresses until completion. With each seed unique to every simulation run, this visualization allows the analyst to set the seed and "play back" any desired simulation. The ability to intuitively build a model, incorporate human-like behavior, and visualize simulation runs made MANA the ideal medium to investigate a warfighter's susceptibility and survivability on the battlefield for various load conditions.

## C. SCENARIO

This section describes the model scenario using a condensed operation order to provide the reader with an overall awareness of the situation, mission, and execution of the model environment. The scenario was made to highlight the effects of weight of a combat load with various levels of ballistic protection. Sections of the operation order that do not apply to the scenario were removed: (1) administration and logistics and (2) command and signal. For more information on combat orders, see Combat Orders Foundations published by Marine Corps Training Command. This operation order is fictional and used for modeling purposes only.

### 1. Orientation

Throughout the last three months, the number of attacks has increased against the local population of a small town, referred to as "Town Z" (Figure 3). The residents have been supportive of U.S. forces in the region and have asked for additional protection from insurgents, who are believed to be hiding among the populace. Supplementary dismounted squad patrols in and around the town have been tasked to strengthen the presence of American forces in the region.

The area has rugged desert terrain with valleys and mountainous regions. Town Z is located against a hill to the northeast and on all other sides is surrounded by flat desert with sparse vegetation (Figure 3). The sand is thin and compact with little micro terrain, which provides zero cover and concealment. The region has a dry climate with little rainfall, variable winds, hot summers, and cold winters. Visibility is unrestricted except during periods of high winds when dust can decrease visibility.


Figure 3. Town Suffering from Insurgent Attacks (Town Z). Adapted from Google Earth (2018).

## 2. Situation

### *a. Enemy Forces*

Over the last 24 hours, a fireteam-sized (typically four) element of insurgents was seen threatening a local family for information about American troop movements. These fighters blend in with the local populace, carry small arms (AK-47 assault rifles), and use cell phones for communication. They have the ability to attack and defend from anywhere inside the town, using buildings and walls to conceal themselves and move between positions. They are unlikely to be reinforced, since intelligence reports indicate the larger force is spread thin with small elements in many towns across the region. Their most likely course of action is a surprise attack, fighting to the death to inflict maximum casualties.

### *b. Friendly Forces*

The platoon's mission is to conduct 24-hour patrolling operations in and around Town Z in order to control the urban region. Marine infantry squads are spread throughout the area, conducting patrols at every town within the AO; the closest patrol is located about 15 miles northwest.

### 3. Mission

At 1000, 1st Squad conducts a dismounted patrol in vicinity of Town Z in order to control the urban region and deny the enemy the ability to harm the local populace. Be prepared to clear the town if the enemy breaks contact after engagement.

### 4. Execution

#### *a. Commander's Intent*

The purpose of this mission is to protect the inhabitants of Town Z and reassure them that U.S. forces are committed to their safety. The enemy's center of gravity (key strength) is their small size and maneuverability, enabling them to blend in with the local population and conceal their movement. Their critical vulnerability (key weakness) is their inability to decisively engage elements that are squad-sized or larger. This will be exploited by patrolling to locate, close with, and destroy enemy forces within the AO.

#### *b. Concept of Operations*

The squad will insert via convoy and will dismount approximately 100 meters outside of Town Z. Upon disembarkation, the squad will first patrol around the town's perimeter, then through the city streets, in a squad wedge formation (Figure 4). Upon patrol completion and reentry of friendly lines, the patrol leader will debrief with the company's intelligence representative. The rest of the execution paragraph of the operation order is omitted for simplicity.

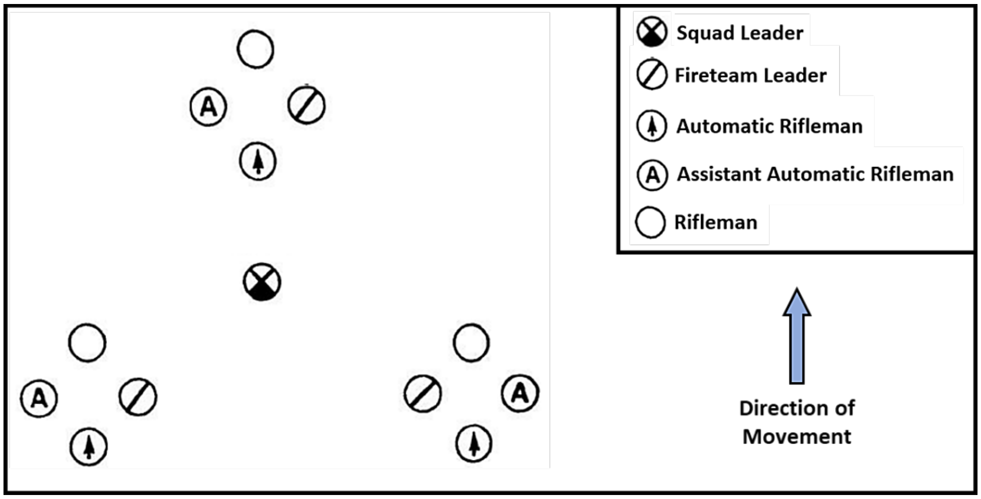


Figure 4. Squad Wedge Formation. Adapted from DN (1991).

Figure 4 shows the squad wedge formation with the specific positions of each Marine by billet. Descriptions of each billet are discussed in detail in Chapter III.E. Squad wedge is used when the enemy situation is unknown because it provides all-around security, facilitates transitions to other formations, and is easy to control for the squad leader (DN 1991).

## D. CREATING THE SCENARIO IN MANA

In MANA, agents are put on the same "team" by setting their allegiance to the same value as all the other agents on their side. For this scenario, only two allegiances were used to indicate either friendly or enemy, which are graphically depicted by the colors blue and red, respectively. Throughout the rest of this thesis, a Blue agent refers to a Marine and a Red agent denotes an enemy fighter.

An agent's physical and behavioral characteristics are determined by states. The default state is the primary state for each agent in a squad. An agent will transition out of the default state and into another based on a battlefield event. These event-driven states in MANA, called trigger states, alter agent behavior to properly "react" to an event, such as taking cover after being shot at (McIntosh et al. 2007).

From the scenario described in the operation order, the Marine rifle squad has dismounted the convoy and is patrolling the perimeter of the town. The simulation begins when the Marines, located 100 meters outside the town, take contact from four enemy fighters. Figure 5 shows the starting positions of each Blue and Red agent as it appears in the MANA graphical user interface.

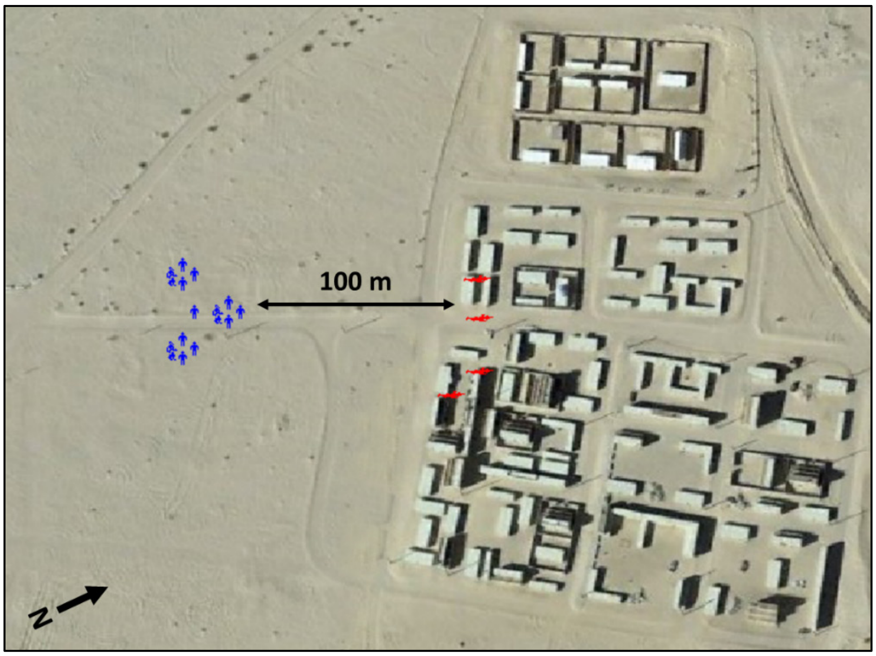


Figure 5. Graphical Depiction of Simulation Start Point.

### 1. Model Assumptions

The development of any model requires assumptions. These may be required due to the situation and environment being modeled, or software limitations. The following assumptions were made for the thesis scenario:

- Enemy agents have no body armor. For the given scenario, the enemy force does not have the resources to distribute PPE to their fighters.
- After taking a shot, a Red agent cannot transition to a new state until after one second. This represents reaction time.

- When shot at, whether hit or not, Red agents are suppressed for six seconds before being able to fire again. This is an estimation of how much time an enemy fighter would hide completely behind cover before re-engaging.

- Blue agents are never suppressed. It is assumed that Blue agents know their best chance of survival is to close with and destroy the enemy with fire and maneuver as quickly as possible due to their exposure.

- Probability of a Blue agent hitting a Red agent partially obscured behind cover is the same as the probability of hitting an agent who is in the prone firing position. This is based on an assumption that an enemy fighter would only expose their head and weapon to fire at a Blue agent through a window. Probability of hit is discussed in detail in Chapter III.E.

- Agent movement and visibility are unaffected by terrain. This is due to the flat desert terrain and an assumption of clear visibility.

### 2. Blue Agent States

For the thesis model, there are four Blue agent states. These states are cyclic, shown in Figure 6. A Blue agent will run for six meters (default state), transition to the prone firing position (reach waypoint state), then get up from prone (spare 1 state), and begin running once again (default state). The only exception to this cycle is when a Blue agent reaches the town, which ends the simulation (reach final waypoint state). The physical performance of a Blue agent in the default and spare 1 states was determined by the weight of the external load, described in detail later in this section. The remainder of this section describes each state under the heading format "Agent Action (State Name)."

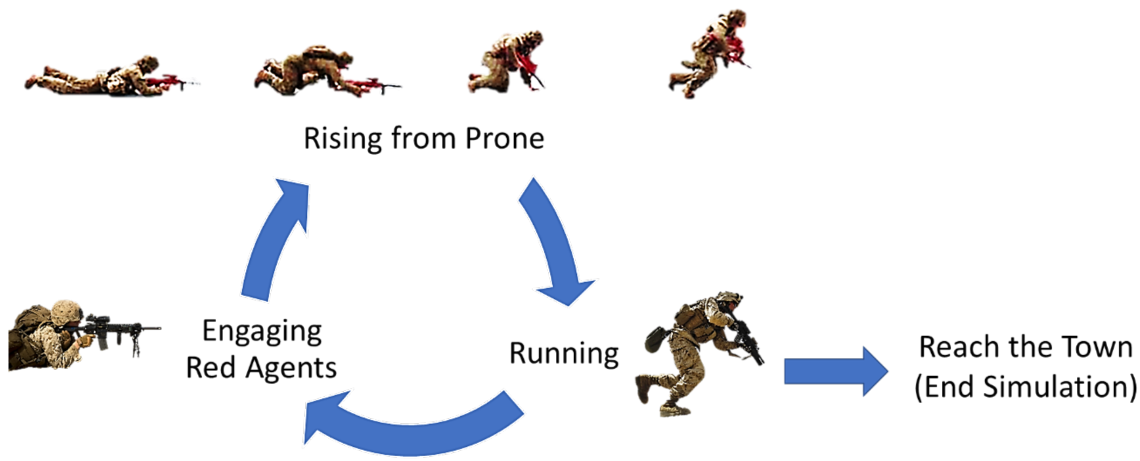


Figure 6. Blue Agent State Cycle.

#### *a. Running (Default)*

In the default state, Blue agents run to their next waypoint, which simulates the rush portion of the buddy rush sequence described earlier. For each agent, their waypoints are spaced in six-meter intervals based on the Hunt et al. study on tactical combat movements (2016). The agent's weapon is disabled in this state, so they are unable to engage enemy fighters. The agent's run speed is constant, which is explained in detail in Chapter III.E.

#### *b. Rising from Prone (Spare 1)*

In this state, Marines have stopped firing at the enemy and are rising from the prone position, transitioning into a sprint; the agent's weapon is disabled. In order to estimate the amount of time it takes based on the weight of the external load carried, previous research was leveraged. An Australian study recorded the amount of time it took for 17 infantry soldiers to complete this movement under six load conditions: military clean skin (MCS) and tiers 0 – 4 (Peoples et al. 2010). The average time for each load condition was calculated and is presented in Figure 7.

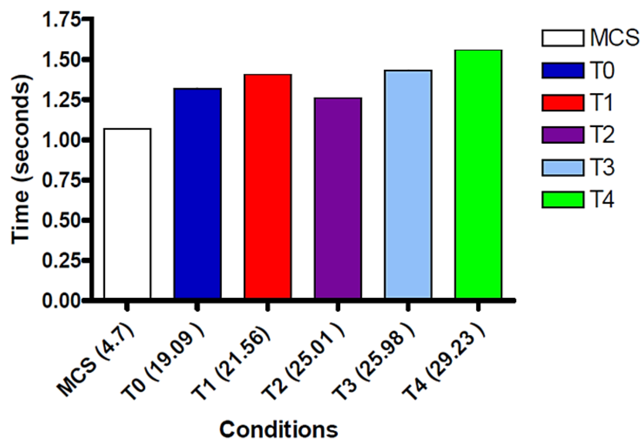


Figure 7. Mean Prone to Feet Time for Six Load Conditions (kg). Adapted from Peoples et al. (2010).

Using this bar chart, the average time to transition from a prone position to a sprint was determined and recorded (Table 4). A logistic regression on this data was run to estimate the transition time, given a specific external load weight (Figure 8).

Table 4. Estimated Mean Time to Feet by Load Condition. Adapted from Peoples et al. (2010).

| **Load Condition** | **Weight [kg]** | **Weight [lbs]** | **Mean Time to Feet [sec]** |
|---|---|---|---|
| MCS | 4.7 | 10.36 | 1.04 |
| T0 | 19.09 | 42.09 | 1.28 |
| T1 | 21.56 | 47.53 | 1.41 |
| T2 | 25.01 | 55.14 | 1.25 |
| T3 | 25.98 | 57.28 | 1.44 |
| T4 | 29.23 | 64.44 | 1.53 |

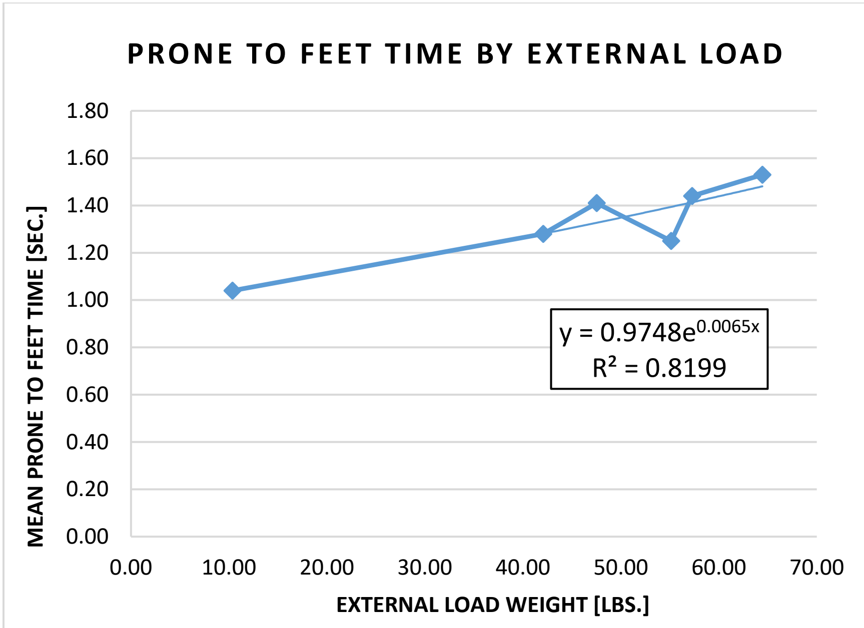


Figure 8. Logistic Regression for Prone to Feet Time for Various Load Conditions.

The resulting equation (Equation 1) was used to determine the spare 1 duration time based on an agent's external load. In this equation, the input $w_{lb}$ represents the total external load in pounds and the output $t_{spare}$ is the average transition time in seconds. Unfortunately, state durations in MANA, when specified, can only be in whole seconds. Due to this limitation, the time determined from this equation was then rounded to the nearest whole second for input to MANA, shown by

$$t_{spare} = 0.9748e^{0.0065 w_{lb}} . \quad (1)$$

#### *c. Engaging Red Agents (Reach Waypoint)*

When an agent has reached a waypoint, the agent moves into the prone firing position. The agent's weapon is enabled and they are engaging Red agents, killing, incapacitating, or suppressing them. The duration of this state is 15 seconds. This affords time for the Marine's buddy—who they are providing covering fire for—to complete their six-meter rush and begin suppressing the enemy.

Each waypoint was spaced in six-meter intervals to replicate the fire and movement sequence in the Hunt et al. study (2016). The waypoints for one of the Blue agents are shown in Figure 9. The waypoints are numbered in descending order, from left to right. The agent starts at point H0—which represents "home"—and proceeds to the first waypoint in the sequence (highest numbered waypoint). The agent proceeds to each waypoint until they are either incapacitated or reach waypoint 0.

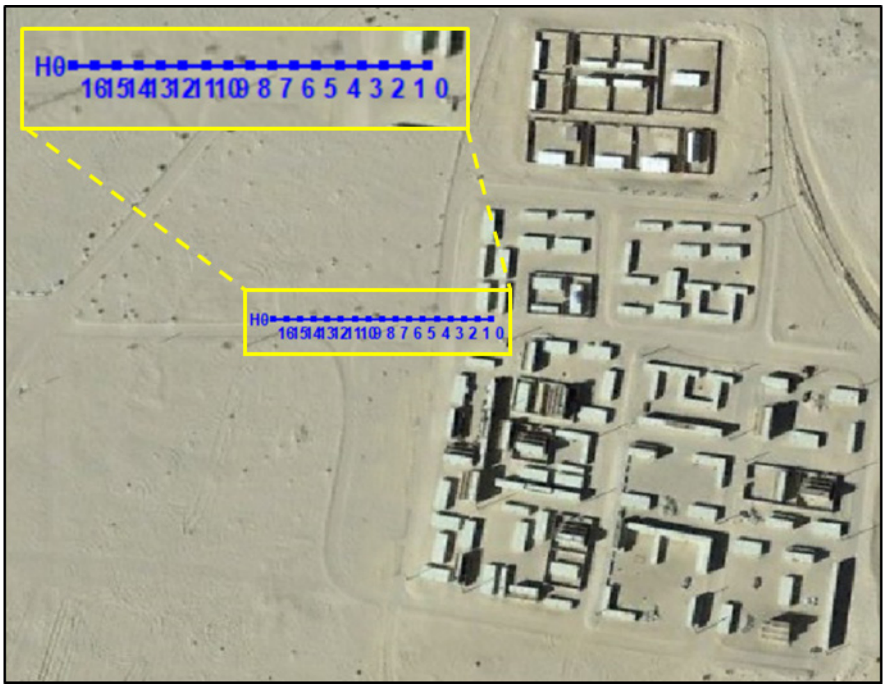


Figure 9. Waypoints for a Blue Agent.

### *d. Reach the Town (Reach Final Waypoint)*

Once any Blue agent reaches their final waypoint (waypoint 0), the simulation terminates. Casualty and time data for the simulation are recorded for analysis. Casualty data is recorded by allegiance (Red or Blue) and agent type. For this model, all Red agents are the same type and each Blue agent is different.

### 3. Red Agent States

There are three Red agent states for the thesis model. Unlike with Blue agents, the Red agent states were strictly event-driven based on how the battle unfolded. This section describes each state in detail under the heading format "Agent Action (State Name)."

#### *a. Acquiring a Blue Agent Target (Default)*

In the default state, a Red agent is looking for a Blue agent to fire at. The agent's weapon is enabled in this state, so once a Red agent identifies a Blue agent as a target, the Red agent begins firing.

#### *b. Firing at a Blue Agent (Taken Shot)*

This state is triggered each time a Red agent fires at a Blue agent. The amount of time an enemy fighter would take to react to being shot at and hide behind cover was estimated as 0.5 seconds. Since MANA requires states other than the default state to be in whole seconds, the state duration was rounded to one second.

#### *c. Taking Fire from a Blue Agent (Shot At)*

This state is triggered when a Blue agent fires at a Red agent. In terms of the simulation, it means one of two things: (1) a Blue agent fired at, but did not hit, a Red agent, or (2) a Blue agent hit a Red agent, but did not incapacitate that agent. When a Red agent transitions into this state, it represents the enemy fighter moving behind cover—invulnerable to Blue fire. This state has a duration of six seconds, during which the Red agent's weapon is disabled. The time spent in this state is an estimation of how long an enemy militant would hide behind cover before re-engaging.

## E. BLUE AGENT CHARACTERISTICS

This section provides an overview of the Marine rifle squad formation (wedge), squad billets, and a detailed description of the Blue agents in the MANA scenario. Infantry demographic data, as of September 2018, and results from a study on tactical combat movements were used to determine agent characteristics. Specifically, physical fitness and marksmanship data were used from all active duty Marines designated as a rifleman (0311 MOS) with a rank of Sergeant (E5) or below.

Recall from the operation order given in the scenario section (Chapter III.C), the Marine rifle squad was to patrol in a squad wedge formation. The wedge formation shown in Figure 4 was incorporated into MANA with agents positioned according to their squad billet (Figure 10). The agent's billet determined not only their position in the squad, but also their weapon, marksmanship skill, and physical fitness level, each discussed below.

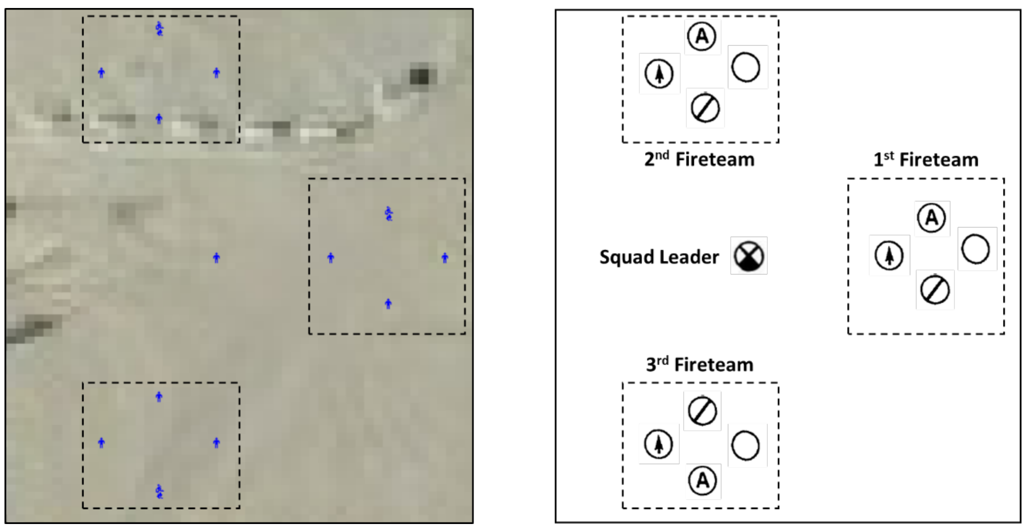


Figure 10. Marine Rifle Squad Formation in MANA.

### 1. Squad Billets

The 13-Marine rifle squad depicted in the thesis scenario has a squad leader with three fireteams of four Marines each. Each fireteam has a rifleman, automatic rifleman, assistant automatic rifleman, and fireteam leader. Each of the five billets has a specific purpose that cohesively make the Marine rifle squad an effective fighting force.

#### *a. Squad Leader*

The squad leader is responsible for the "tactical employment, fire discipline, fire control, and maneuver" of the squad (DN 1991). The squad leader is a non-commissioned officer (NCO), usually a Sergeant. In this scenario, the agent representing the squad leader is equipped with an M4 rifle.

#### *b. Fireteam Leader*

Similar to the squad leader, the fireteam leader is responsible for the employment of the three Marines under their charge. They are positioned where they can best control the fires of the automatic rifleman as well as communicate with the squad leader. The fireteam leader is an NCO, usually a Corporal (E4), who executes the orders of the squad leader. In the thesis scenario, the fireteam leader is equipped with an M4 rifle.

#### *c. Automatic Rifleman*

As the primary offensive capability of the fireteam, the automatic rifleman is responsible for the employment and maintenance of their automatic weapon (DN 1991). They usually have the rank of a Lance Corporal (E3) and are equipped with an M27 IAR.

#### *d. Assistant Automatic Rifleman*

The assistant automatic riflemen, typically a Lance Corporal, works with the automatic rifleman as a team. Assistance is usually in the form of carrying additional ammunition for the M27 IAR. At any time, the assistant automatic rifleman must be ready to assume the position of automatic rifleman, in case that Marine is injured or killed. The thesis scenario equips this billet with an M4 rifle.

#### *e. Rifleman*

As the lowest ranking member of the squad, the rifleman is trained as a scout and put at the forward edge of most formations (DN 1991). Since they have the rank of either a Private (E1) or Private First Class (E2), they are only responsible for carrying out the orders given to them by their fireteam leader and effectively engaging the enemy with their rifle. In this thesis scenario, the rifleman uses an M4 rifle.

### 2. USMC Active Duty Infantry Demographic Data

In order to make the MANA agents reflect the Marines they are attempting to represent, infantry demographic data was collected on every active duty Marine rifleman (E5 and below), over 14,000. This data set was analyzed and summary statistics were generated to be used for calculating appropriate inputs for agent properties (Table 5).

Table 5. Summary Statistics for Active Duty Marine Riflemen.

| | CFT | | | Rifle | | |
|---|---|---|---|---|---|---|
| **Grade** | **N** | **Average** | **IQR** | **N** | **Average** | **IQR** |
| E1/2 | 3110 | 265.1 | [252, 287] | 2745 | 302.1 | [293, 316] |
| E3 | 16493 | 276 | [267, 293] | 14003 | 301.2 | [293, 319] |
| E4 | 12582 | 286.8 | [282, 298] | 10066 | 308.3 | [300, 322] |
| E5 | 8909 | 288.7 | [285, 300] | 7041 | 309.2 | [301, 324] |

In Table 5, the interquartile range (IQR) represents the middle 50 percent of the data, displayed as [lower quartile, upper quartile]. The *N* represents the sample size (number of data points) used to calculate the average CFT and rifle range scores. The sample size is larger than may be expected because the CFT and rifle qualification are completed annually; therefore, the data collected includes every one of these events each Marine completed since entering service. This resulted in multiple scores for each Marine.

For context, the maximum score a Marine can achieve when running the CFT is 300, and a failure results in a score of zero. To earn a score of 285 or higher is considered an excellent achievement and with it comes an exemption from body fat percentage and weight limits (United States Marine Corps 2019). For rifle range qualification, a perfect score is 350. If a Marine fails to qualify—does not achieve the minimum score of 250—their score is recorded as a zero. When a Marine qualifies, they are given a specific marksmanship designation based on their score:

- 305 – 350: Expert
- 280 – 304: Sharpshooter
- 250 – 279: Marksman

### 3. Marksmanship

Multiple factors were incorporated to determine the probability a Blue agent inflicts a Red casualty, the MANA probability of hit—MANA P(H). The type of weapon fired, the distance from shooter to target, the area of the target, the level of body armor worn by the target, and the shooter's rifle qualification score were all used. For this model, the MANA P(H) is actually probability of incapacitation, *P(I)*. This value was determined using *P(H)* and probability of incapacitation given a hit, *P(I|H)*, data from Army Material Systems Analysis Activity (AMSAA). The methodology for estimating *P(H)* and *P(I|H)* for Blue agents is summarized below.

To calculate *P(H)*, AMSAA used the weapon type, munition fired, distance to target, and area of the target (Way 2014). For Blue agents, the weapon type was either an M4 rifle or M27 IAR, which both fire 5.56 mm ammunition. The target distance used was 100 meters. The area of the target, assumed to be stationary, was based on the target's position, either standing, kneeling, or prone. For the thesis model, the prone target was used since its area is based on the head, which is what is assumed to be exposed for a Red agent when firing, either from a window or around a corner. Each *P(H)* was then multiplied by a marksmanship factor based on each Marine's rifle qualification score. This factor was computed by dividing the average score for each rank (grade) by the maximum score (350). These values are summarized in Table 6.

Table 6. Marksmanship Factor by Grade.

| Grade | Billet | Weapon | Rifle | Marksmanship Factor |
|---|---|---|---|---|
| E1/2 | Rifleman | M4 | 302.1 | 86.3% |
| E3 | Auto Rifleman<br>Assist Auto Rifleman | M27<br>M4 | 301.2 | 86.1% |
| E4 | Fireteam Leader | M4 | 308.3 | 88.1% |
| E5 | Squad Leader | M4 | 309.2 | 88.3% |

To calculate *P(I|H)*, AMSAA added an additional factor to their calculations—the level of body armor worn by the target (Way 2014). For a Blue agent firing at a Red agent, *P(I|H)* was very high, since the shot is assumed to be to the head; at 100 meters, this value was 99 percent. The probability that a shot fired by a Blue agent will incapacitate a Red agent, *P(I)*, was calculated using Equation 2, where

$$P(I) = P(H) \times P(I \mid H). \tag{2}$$

It is important to note that incapacitation does not distinguish between wounded and killed in action (KIA). The results reflecting Blue and Red casualties therefore cannot be further broken down into number of killed and wounded. For Red casualties, the results can only be viewed as a best case (all killed) or worst case (all wounded) scenario; reverse cases for Blue casualties.

#### 4. Physical Performance

A Marine's fitness level significantly affects how well that Marine performs during physically demanding tasks. Sprinting under enemy fire while wearing a combat load exemplifies one of those tasks. In the MANA simulation, this task corresponds to when an agent is in the default state. To calculate a Blue agent's speed in the default state, an initial speed was calculated and then fitness was incorporated based on the agent's squad billet.

The speed at which a Marine is able to run a six-meter bound while wearing an external load was calculated using Equation 3 (Hunt et al. 2016). In this linear regression equation, $w_{kg}$ represents the weight carried in kilograms and $t_b$ the time to complete the six-meter bound in seconds. The average bound speed (in meters per second) was calculated by dividing the bound length (six meters) by $t_b$, where

$$t_b = 0.04w_{kg} + 3.294. \tag{3}$$

The Hunt et al. study also showed that, on average, there was a 1.1 percent performance decrement in speed per kilogram of external load from the beginning to the end of the 16 six-meter bound sequence (2016). Similarly, the fastest and slowest participants of the study had performance decrements of 0.8 and 1.4 percent, respectively (Hunt et al. 2016). This infers that physical fitness played a role in performance. To incorporate this into the simulation, CFT scores were used as the indicator of fitness level and partitioned into groups:

- Score ≥ 285:  Fast Group (0.8% per kg decrement in speed)
- 250 ≤ Score < 285:  Average Group (1.1% per kg decrement in speed)
- Score < 250:  Slow Group (1.4% per kg decrement in speed)

Using the Marine's rank based on squad billet, the average CFT score for that rank was used to determine which group that Marine was a part of. This was done for each billet in the squad, with the results summarized in Table 7.

Table 7. Performance Decrement by Squad Billet.

| Grade | Billet | Avg CFT | % / kg Dec |
|---|---|---|---|
| E1/2 | Rifleman | 265.1 | 1.1 |
| E3 | Auto Rifleman<br>Assist Auto Rifleman | 276 | 1.1 |
| E4 | Fireteam Leader | 286.8 | 0.8 |
| E5 | Squad Leader | 288.7 | 0.8 |

CFT ≥ 285:  Fast Group (0.8% / kg decrement)
250 ≤ CFT < 285:  Average Group (1.1% / kg decrement)
CFT < 250:  Slow Group (1.4% / kg decrement)

Based on the CFT score delineations, none of the Marines fell into the slow group. Each Blue agent representing a rifleman, automatic rifleman, or assistant automatic rifleman had a 1.1 percent per kilogram of load speed decrement factored into their default state speed. The Blue agents simulating the squad leader and fireteam leaders had a 0.8 percent per kilogram speed decrement applied to their default state speed.

Since the study results were based on 16 rushes and not all Blue agents have exactly 16 waypoints, a slight modification to the calculations was needed. The solution was to use Excel's Goal Seek function with a compound decrement formula, where

$$speed_{16} = speed_0 (1 - rate)^b \, . \tag{4}$$

In Equation 4, $speed_0$ is the Blue agent's starting speed of the first six-meter bound and $speed_{16}$ is the speed after the sixteenth rush is complete, both in meters per second. The percent decrement between those two values was either 0.8 or 1.1 percent per kilogram of external load, as discussed previously. The *rate* is the speed decrement rate between each bound—this is what was solved for using Excel's Goal Seek function. Variable *b* represents the bound number (e.g., speed of the first bound has $b = 1$).

First, to determine each Blue agent's running speed, Equation 3 was used to calculate the speed of the first rush. Then, the Excel function was used to determine the decrement rate between each rush in order to achieve the desired percent decrement per kilogram between the first and sixteenth rushes, either 0.8 or 1.1. Once solved for, this rate was used to calculate the speeds of subsequent rushes if that particular Blue agent had greater than 16 waypoints. Lastly, the average speed of all rushes was calculated and input as the default state speed for the Blue agent.

### 5. MANA Input Data Summary

The collection and analysis of demographic data, as well as previous research, was done in order to determine scientifically-based inputs for MANA. The Blue agent inputs determined from the data analysis were the rising from prone (spare 1 state) duration, agent running (default state) speed, and MANA P(H). Figure 11 shows the flow of information used to calculate the value of each input.

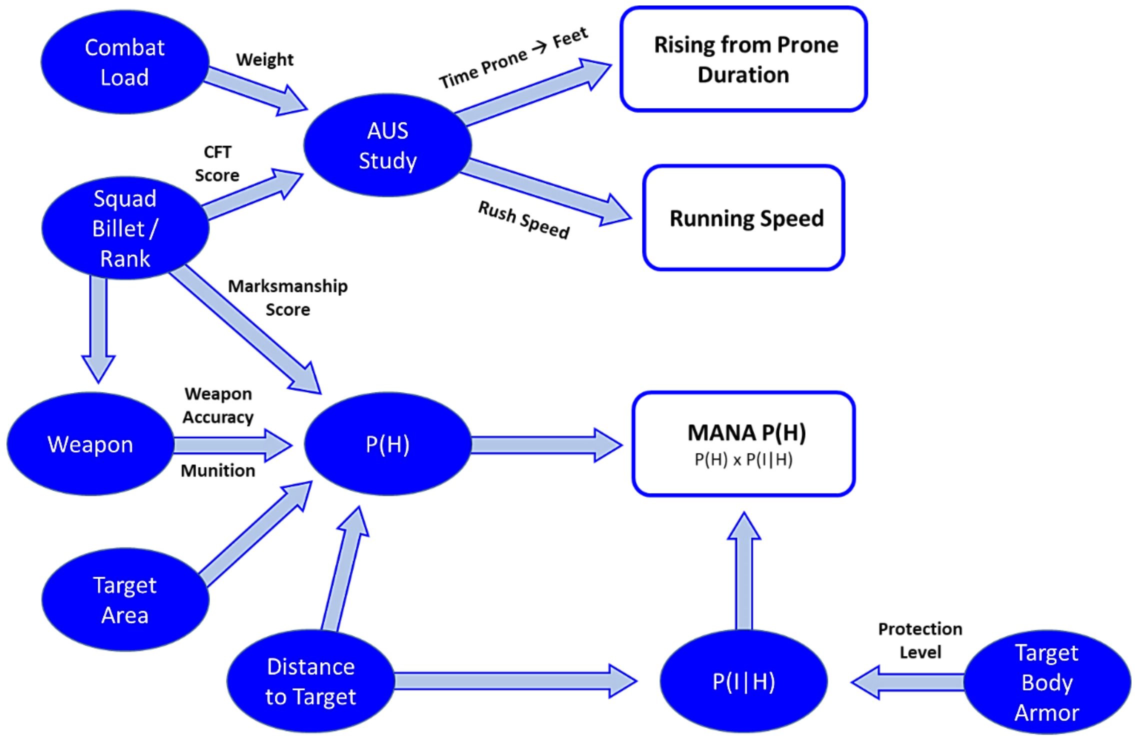


Figure 11. Flow of Data Incorporated into Blue Agent Characteristics.

For example, the combat load carried provided a weight to be used in equations for calculating the rising from prone duration and the agent's running speed in the default state. Similarly, a Marine's billet in the squad determined their rank, which was used to determine their average CFT and rifle scores. These scores were incorporated into equations for the agent's running speed and probability of hitting a target.

## F. RED AGENT CHARACTERISTICS

The only MANA input for Red agents was their MANA P(H). The same AMSAA methodology was used to calculate these values for Red agents inflicting Blue casualties. The weapon type for Red agents was the AK-47 (7.62 mm ammunition). Due to the different Blue agent states and body armor levels worn, the calculation process was more complex. When a Red agent fires a shot, the Blue agent's state at the time affects *P(H)* and the Blue agent's body armor level affects *P(I|H)*.

Since Blue agents were simulated running directly towards the Red agents, the AMSAA data used to calculate probability of hit was for stationary targets. The moving target data available was for lateral movement, so the stationary data was deemed to be a more accurate representation of the simulation. Based on agent state, the target area presented for a Red agent to aim at changed, affecting *P(H)*. The only Blue agent state unaffected was the reach final waypoint state, since that state ended the simulation. For each Blue agent state, the following estimated target areas were used to calculate the probability that a Blue agent was hit by a Red agent, *P(H)*:

- Running (Default State): Standing Target
- Engaging Red Agents (Reach Waypoint State): Prone Target
- Rising from Prone (Spare 1 State): Kneeling Target

Based on the level of body armor worn by a Blue agent, the *P(I|H)* changes. To calculate this conditional probability, AMSAA used a combination of the proportion of body area protected by the body armor and its NIJ level (Way 2014). Once computed, Equation 2 was used to determine *P(I)*, which was input as MANA P(H) for the Red agents. It is important to note that a marksmanship factor was not incorporated for Red agents, as was the case for Blue agents. A summary of the factors used to calculate the Red agents' MANA P(H) is shown in Figure 12.

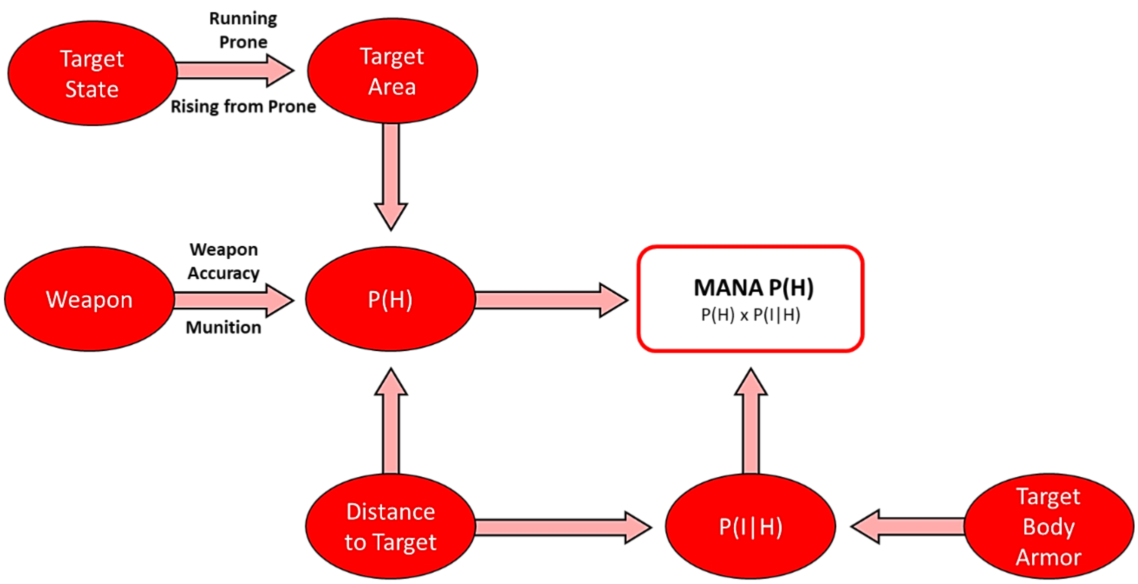


Figure 12. Flow of Data Incorporated into Red Agent MANA P(H).

## G. LIMITATIONS

As with any computer simulation, there are limits to how accurately the desired real-world scenario can be modeled. One limitation identified during the model-building process is that MANA state durations have precision restricted to the nearest whole second. Although the time step (amount of time elapsed in the simulation between agent state updates) is one tenth of a second, state durations cannot be in tenths of a second. This restriction reduces the accuracy of the time a Blue agent spends in the spare 1 state (rising from prone).

Another limitation of MANA that forced a simplification of input data is that an agent's state speed must be a single value, which affected the agent's running (default) state. In reality, warfighters executing a six-meter rush starting from the prone position first accelerate, then decelerate before returning to the prone position. MANA does not readily allow acceleration and deceleration of an agent in a given state. This limitation results in the speed of each agent reflecting an estimation of the average speed attained during each bound over the course of the entire rush distance.

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# IV. DESIGN OF EXPERIMENTS

This chapter describes the design of experiments (DOE) used to explore the effects of various factors on casualties and mission success for the thesis scenario. Chapter IV.A discusses the full factorial and nearly orthogonal Latin hypercube (NOLH) designs, a space-filling and efficient design developed at the Naval Postgraduate School (Cioppa and Lucas 2007). Chapter IV.B discusses the experiments conducted and factors incorporated in each.

## A. UTILIZING THE OLD AND THE NEW: FULL FACTORIAL AND EFFICIENT DESIGNS

In search of answers to questions, DOE is used to scientifically explore causes and effects with little to no risk of confounding (hidden effects on an outcome), ensuring the validity of conclusions. Similar in importance to problem framing during military planning, understanding the goal of the experiment is vital to determining the proper design of experiments. Once the goal is established, the variables that represent the quantitative (numeric) or qualitative (non-numeric) measure of that goal are identified; these are called response variables. Any factors (inputs) that may affect the response are determined and appropriate values, called factor levels, are assigned; these levels may be nominal, discrete, or continuous over a specified range. Once the levels of each factor are identified, the number of design points (unique combinations of factor levels) can be calculated. For this thesis, two types of DOE are used: a full factorial and a 33-design point NOLH.

A full factorial design explores all possible combinations of factor levels. A nearly orthogonal Latin hypercube has properties similar to a full factorial design, but requires orders of magnitude fewer experimental runs (Sanchez 2006). Depending on the number of factors and levels, using a NOLH may take a few hours, whereas using a full factorial would take years. Due to the low number of factors and factor levels, as well as the relative simplicity of the simulation model, this thesis used full factorial designs for Experiments 1 and 2. For Experiment 3, a 33-design point NOLH was used to efficiently explore the experimental region due to having three continuous factors. Each experiment is discussed in detail in Chapter IV.B.

## B. EXPERIMENTS

The objective of this thesis was to obtain an understanding of how the combat load can both enhance and diminish the effectiveness and survivability of the warfighter. To accomplish that objective, the metrics of interest (response variables) were the number of Marine casualties and probability of mission success. Mission success in this scenario was at least one Blue agent reaching their final waypoint, signifying they have reached the town and will conduct follow-on operations.

To account for model variability, the number of replications to run per design point was determined by calculating the sample size ($n$) required to declare a statistically significant difference between groups via a hypothesis test, where the difference between their means is at least delta ($\delta$). The formula used was

$$n = \left[ \frac{\sigma(|Z_\alpha| + |Z_\beta|)}{\delta} \right]^2 . \tag{5}$$

A hypothesis test is a statistical method used to determine whether we would reject or fail to reject a null hypothesis, given the collected data and our desired levels of confidence and power. For this thesis, an example of a hypothesis is: increased combat load weight has no impact on the number of Marine casualties. In Equation 5, the standard deviation ($\sigma$) was estimated to be 2.9 casualties after conducting 1,000 simulation runs of the base case—discussed later—and the difference to detect ($\delta$) was set at 0.25. The Z-scores (number of standard deviations away from the mean) of a normal distribution, $Z_\alpha$ (1.96) and $Z_\beta$ (0.84), are for a hypothesis test with a five percent significance level ($\alpha$), also known as 95 percent confidence, and 80 percent power ($1 - \beta$); these are commonly used values for confidence and power. The significance level means there is a five percent chance of making a type I error (false positive). An example of a false positive would be concluding that increased combat load weight affects casualties when it truly doesn't. A test with 80 percent power means there is a 20 percent chance ($\beta$) of making a type II error (false negative). An example of a false negative is concluding that increased combat load weight does not affect casualties when it truly does. The required sample size calculated is 1,055, but for this thesis, the number of replications done per design point was set at 1,000. This was done because detecting a mean difference of exactly 0.25 was not essential for analysis; 1,000 replications still detects a mean difference of less than 0.30.

### 1. Experiment 1: Standard Loads and Body Armor Levels (Base Case)

The first experiment was used to explore the effects of the Marine Corps' current standard loads and body armor levels. Insights from this experiment can provide Marine leaders at all levels a baseline understanding of the impacts of current standards. The two factors explored were Load Type (fighting or assault) and Body Armor Level (II, III, or IV). The design points for this experiment are shown in Figure 13. Each design point was repeated 1,000 times, resulting in 6,000 total simulated battles.

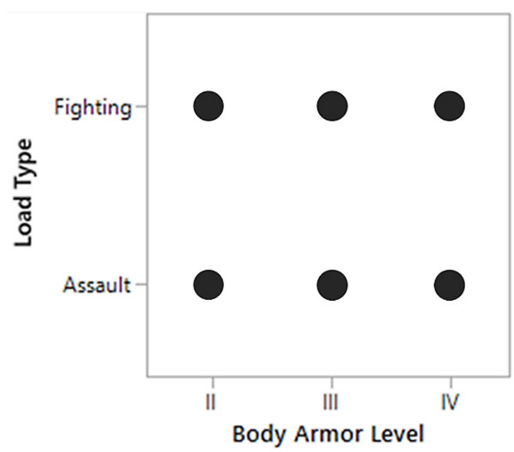


Figure 13. Base Case Experimental Region.

Since the P(H) data used in this study are for stationary targets, an additional factor, Red P(H) Multiplier, was created. This factor was used to represent the reduced probability of a Red agent hitting a moving Blue agent. For example, a Red P(H) Multiplier of 0.5 represents a Red agent firing at a target that is twice as hard to hit as a stationary one, since the new P(H) is half that of a stationary target. This factor was varied from 0.1 to 1.0 in increments of 0.05 (for a total of 19 levels). With the addition of the Red P(H) Multiplier factor, the base case experiment was repeated, again with 1,000 replications per design point, resulting in 114,000 simulated firefights. A summary of the factors, levels, and variable types for Experiment 1 are displayed in Table 8.

Table 8. Experiment 1 Factors, Levels, and Variable Types.

| Factor | Levels or Range | Variable Types |
|---|---|---|
| Load Type | Fighting, Assault | Categorical |
| Body Armor Level | II, III, IV | Ordinal |
| Red P(H) Multiplier | 0.1 - 1.0 | Continuous |

### 2. Experiment 2: External Load and P(H)

Since commanders are able to modify the standard load based on the mission and operational environment, it was important to investigate a wide range of external load weights. It was also important to incorporate the Red P(H) Multiplier to explore its impact on the response variables for varying load weights. For this experiment, the two factors used were External Load and Red P(H) Multiplier. Figure 14 presents the scatterplot matrix of the design points, which make up the experimental region.

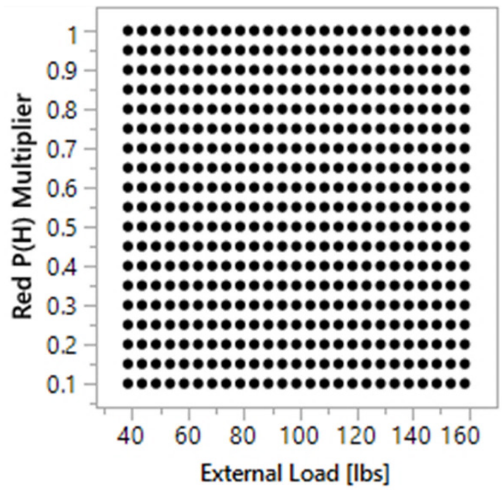


Figure 14. External Load and Red P(H) Multiplier Experimental Region.

To establish a lower bound for the range of External Load, the weight of a helmet, rifle, IFAK, and NIJ body armor level III was used; combined, these total 40 pounds of gear. For an upper bound, 160 pounds was selected based on the GAO report of Marine combat loads referenced in Chapter II.C. The range for External Load used five-pound increments, resulting in 25 levels. For the Red P(H) Multiplier, the same range was used from Experiment 1 (19 levels). Since NIJ body armor level III provides the maximum required protection based on the enemy threat, this was held constant. With a full factorial design, the experimental region had 475 design points, each replicated 1,000 times, for a total of 475,000 simulated firefights. A summary of these factors is shown in Table 9.

Table 9. Experiment 2 Factors, Levels, and Variable Types.

| Factor | Levels or Range | Variable Types |
|---|---|---|
| External Load [lbs] | 40 - 160 | Continuous |
| Red P(H) Multiplier | 0.1 - 1.0 | Continuous |

### 3. Experiment 3: Speed, Prone Time, and P(H) Sensitivity

A sensitivity analysis was done on three of the MANA inputs to explore their impact on the response variables. Since this study was largely focused on the impact of a

Marine's speed during a firefight, one of the factors chosen was a Blue agent's running (default state) speed. The Red P(H) Multiplier factor was also selected for this experiment to understand its influence with respect to changing Blue agent run speed. The final factor chosen for sensitivity analysis was a Blue agent's time spent in the prone firing position (reach waypoint state). This was done to explore the impact of values around the original estimation of 15 seconds.

With three continuous factors, a 33-design point NOLH was selected for the DOE. To reduce the correlation between factors and obtain a more space-filling design, this design matrix was stacked and rotated nine times, resulting in a 289-design point NOLH (Figure 15). Once again, each design point was replicated 1,000 times, totaling 289,000 simulated battles. If this experiment was run with a full factorial DOE—as was done for Experiments 1 and 2—the number of design points would have been 35,937 (three factors with 33 levels each = $33^3$ design points). Running 1,000 replications per design point would have required 35,937,000 simulation runs, significantly more than what is required for the NOLH. With each simulation lasting an average of seven seconds, this experiment would take nearly eight years to complete on a single computer. Instead, using the 33-design point NOLH, rotated and stacked, the 289,000 simulated battles takes only 24 days to complete, reducing the time required by 99 percent. For this thesis, a computer cluster was used to run the experiment, which took less than 4.5 hours.

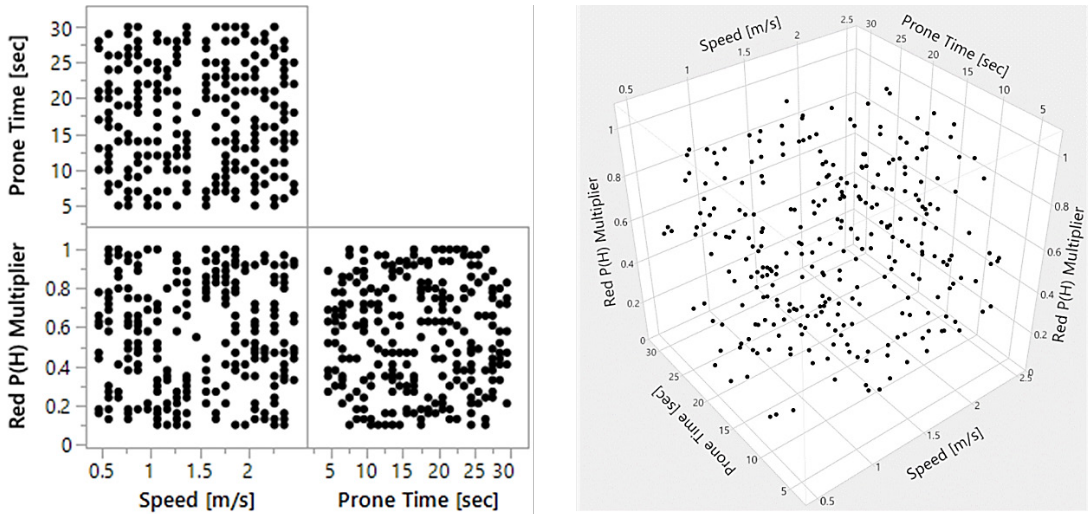


Figure 15. Sensitivity Analysis Experimental Region in 2D (left) and 3D (right).

To determine the range for running (default state) speed, lower and upper bounds were chosen as extreme values. The upper bound was chosen from the Hunt et al. study on tactical combat movements, where the maximum speed achieved during a single bound was approximately 2.5 meters per second (2016). A lower bound of 0.5 meters per second was chosen to represent utter exhaustion. For the Red P(H) Multiplier factor, the same range from Experiments 1 and 2 was used for consistency. The final factor, Prone Time, ranged from 5 to 30 seconds. Table 10 provides a summary of these factors and their values for Experiment 3.

Table 10. Experiment 3 Factors, Levels, and Variable Types.

| Factor | Levels or Range | Variable Types |
|---|---|---|
| Default Speed [m/s] | 0.5 - 2.5 | Continuous |
| Prone Time [sec] | 5 - 30 | Continuous |
| Red P(H) Multiplier | 0.1 - 1.0 | Continuous |

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# V. DATA ANALYSIS AND EXPERIMENT RESULTS

This chapter details the analysis of the output data from each experiment specified in Chapter IV.B. Chapter V.A describes the analytical methods used to explore the impact of each factor, or combination of factors, on the response variables in order to answer the thesis questions. Chapters V.B – V.D provide the results of each experiment.

## A. ANALYTICAL METHODS

Before any analysis can be done, the data must be visualized to determine appropriate analytical methods to apply, based on the sample distribution. Histograms and boxplots are commonly used for this purpose. Not only do they provide insight into the underlying population distribution, critical for analysis, these graphs can also illustrate trends in the data or outliers to be further investigated. Once suitable methods have been selected, they are applied in an effort to understand how the inputs affect the response. Partition trees and linear regressions are used for this purpose.

### 1. Data Visualization: Histograms and Boxplots

A histogram plots the frequency of each value observed for a given variable. Plotting the density (frequency divided by total sample size) of each value gives an analyst a representation of the probability distribution of the population; the larger the sample size, the more accurate the representation. This information can then direct the analyst towards appropriate statistical tests that will yield valid conclusions.

Boxplots use a five-number summary to describe the distribution of sample data. These five numbers are the minimum and maximum, excluding outliers, median, upper quartile, and lower quartile. Outliers are calculated as values 1.5 times the interquartile range (Q3–Q1) greater than the upper quartile (Q3) or less than the lower quartile (Q1). The minimum and maximum are selected as the smallest and largest numbers that do not exceed those thresholds. If no outliers are present, these two values are the true minimum and maximum. The median is the midpoint in the data. The upper quartile is the point at which 25 percent of the data exceeds that value. Similarly, the lower quartile is the point at which 25 percent of the data is below that value. These plots are very indicative of data variability and distribution symmetry.

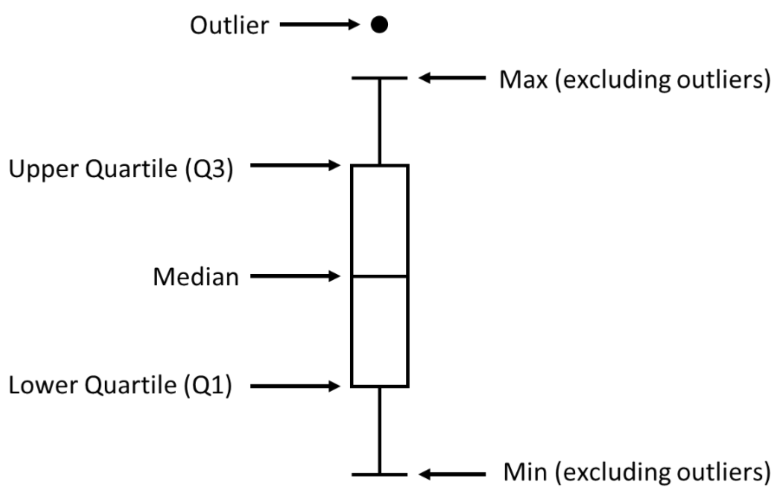



Figure 16. Boxplot Overview.

### 2. Data Exploration: Partition Trees and Linear Regressions

A partition tree (often referred to simply as a tree) is a nonparametric method, meaning it does not require a specific population distribution, used to classify or predict a response. A tree splits the data into homogeneous subgroups called leaves. The data points contained in each leaf are determined using a recursive partitioning regression algorithm, which essentially tries all possible splits and chooses the one with the least amount of error (Faraway 2016). Each leaf estimates the response based on the average of the response values from the data contained within the leaf. Because trees are easy to interpret and quickly identify dominant factors, thresholds, and interactions, trees are an effective tool for communicating analysis.

When creating trees, specific factors dominated the splits for some experiments. This typically happens when a factor has a significant impact on the outcome of the response, regardless of the presence of other factors. In order to make the trees more useful to a commander or decision maker, the number of times a single factor was used for splits was limited; the dominance of the factor was noted for reference.

One of the main uses of regression analysis is to understand the effects of factors on a specific response (Faraway 2015). Linear regressions attempt to predict the value of the response by splitting the data into explained and unexplained components. The explained component is what is estimated from the data using the specified factors. The unexplained component, known as the residual, encompasses the difference between the predicted and actual values of the response (Faraway 2015). Together, these two parts make up the regression model. The goal of this model is to minimize the residual, making the prediction (or fit) as accurate as possible. To accomplish this goal, various methods can be used to solve for the specific values associated with each component. This thesis uses the most common method of least squares.

## B. BASE CASE ANALYSIS AND RESULTS

The focus of the base case experiment was to determine if the increase in weight from the fighting load to the assault load impacts Marine casualties and mission accomplishment. The base case incorporated the three NIJ body armor levels to quantify the effects of various degrees of ballistic protection on the results. Also, because the P(H) data used were for stationary targets, the Red P(H) Multiplier factor was added to the base case DOE to determine its effect on casualties, simulating how a moving target is harder to hit than a stationary one, or to account for enemy fighters of varying marksmanship skill. Additional analysis on the results of these experiments can be seen in Appendix C.

To determine if there was a difference in casualties between the fighting and assault loads, the data was split by load type. Since each repetition of every design point is linked by a common random number seed, the data was analyzed as paired data. The common seed means the first simulated battle with a fighting load and NIJ body armor level II has the same random number seed as the first simulated battle with an assault load with the same body armor level; the “randomness” that starts both firefights is exactly the same. Therefore, the difference in outcome can be attributed to the change in load type. To see how the number of casualties changed from the fighting load to assault load, the casualties taken during each simulated battle using the fighting load was subtracted from its paired simulation using the assault load. Figure 17 displays the resulting casualty difference.

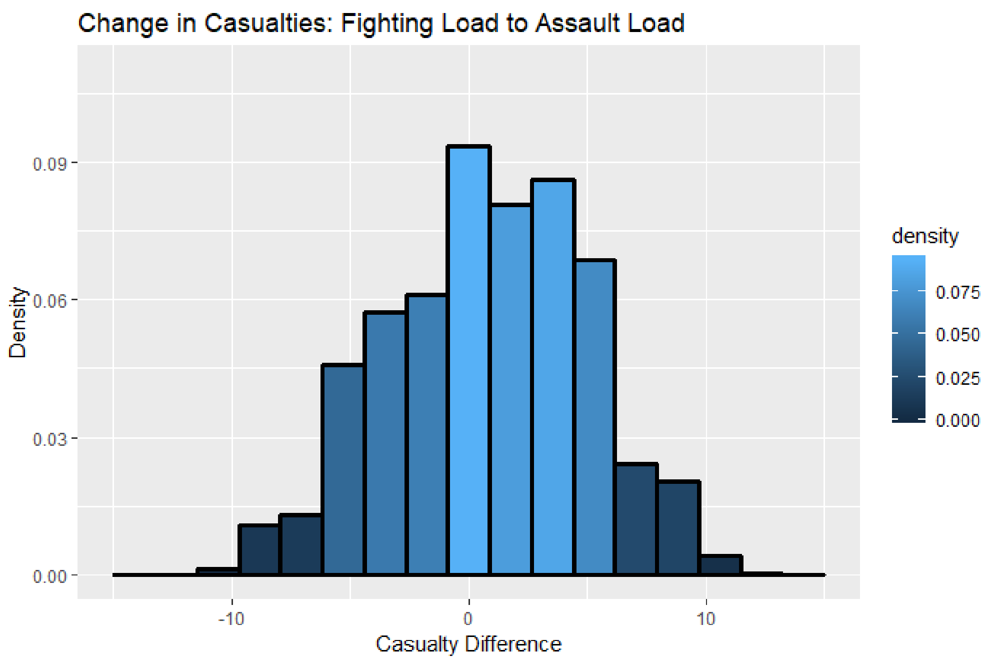



Figure 17. Base Case: Change in Casualties from Fighting Load to Assault Load.

The histogram shows a slight, right skew to the data indicating that, more frequently than not, the number of casualties incurred with the assault load was greater than with the fighting load. A T-test for the average difference in casualties between the fighting and assault loads was 0.787 (p-value < 2.2e-16), which shows that the expected number of casualties with the assault load is greater than the fighting load. It is not surprising that the difference in casualties was not drastic, since the assault load is only 15 pounds heavier than the fighting load. However, it is important to note that an increase in only 15 pounds of external load carried does impact the number of casualties.

To find out just how much of a difference there is between the two loads, as well as the impact of each ballistic protection level, the data was further split by NIJ body armor level; the data groupings now corresponded to the design points from the DOE (Figure 13). The casualty results are displayed with boxplots for each group (Figure 18). The lower quartile, also known as the 1$^{st}$ quartile (Q1), median, and upper quartile, or 3$^{rd}$ quartile (Q3), for each boxplot are presented in Table 11.

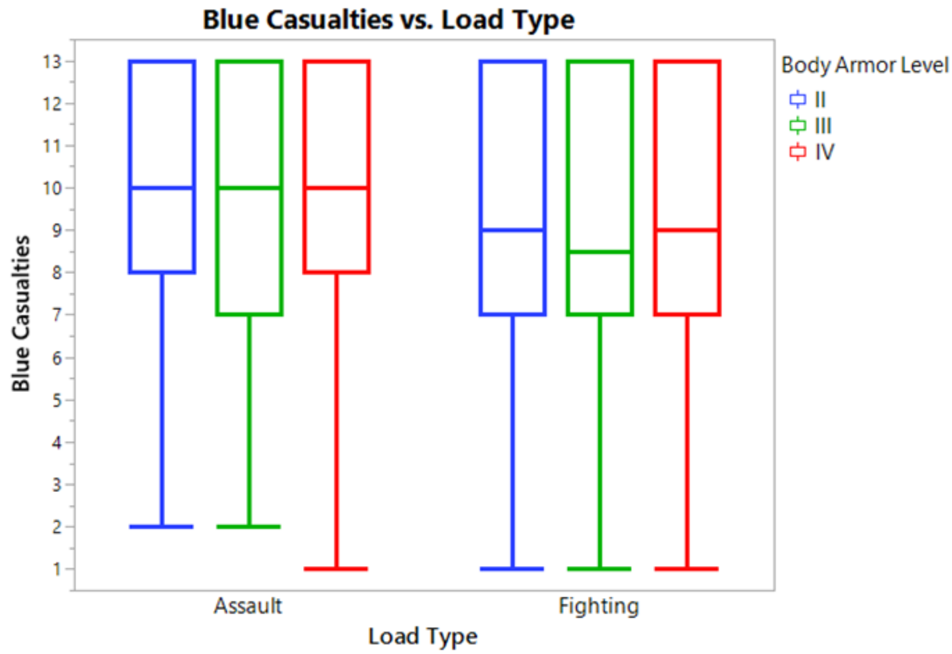



Figure 18. Base Case: Blue Casualties Boxplots by Load Type and Body Armor Level.

The skewness (asymmetry) apparent from the histogram (Figure 17) is also seen in the boxplots, indicated by the decrease in medians from the assault load to the fighting load. On average, there appears to be a decrease of about one casualty when lightening the load, regardless of body armor level, for both the median and lower quartiles (Table 11). It is also noteworthy that the ranges for each boxplot nearly span the entire feasible range—highlighting the impact of pure randomness on this engagement.

Table 11. Base Case: Blue Casualties Boxplot Statistics.

| | Blue Casualties | | | | | |
|---|---|---|---|---|---|---|
| | Assault Load | | | Fighting Load | | |
| Body Armor Level | Q1 | Median | Q3 | Q1 | Median | Q3 |
| II | 8 | 10 | 13 | 7 | 9 | 13 |
| III | 7 | 10 | 13 | 7 | 8.5 | 13 |
| IV | 8 | 10 | 13 | 7 | 9 | 13 |

Since commanders care about both the health of their Marines and mission accomplishment, the probability of mission success was also investigated for the base case. Recall, mission success for a simulated battle was at least one Blue agent reaching their final waypoint, indicating they have reached the town and are prepared to conduct follow-on operations. To achieve greater fidelity in the number of successful missions, an additional 1,000 replications of each design point for the base case was performed. With the data delineated into the same groups, the number of successful missions was totaled and is displayed in Figure 19. Since each design point was repeated 2,000 times, the number of successful missions can be divided by 2,000 to calculate probability of success.

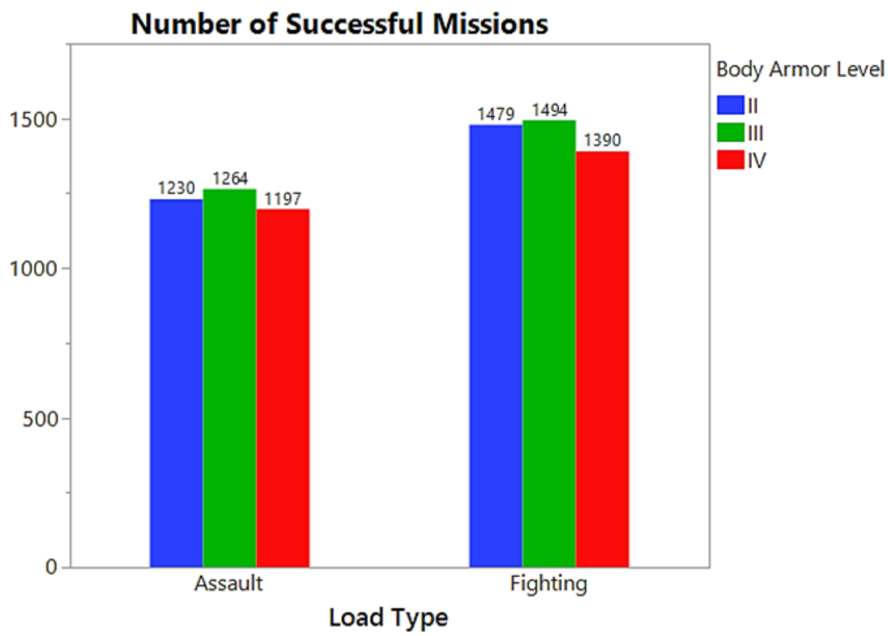



Figure 19. Base Case: Number of Successful Missions.

Looking at both load types, the additional weight from ballistic protection (level II to III) increases the probability of mission success. To get a better idea of the probabilities and their respective standard errors of each load type and body armor level, these values were calculated and compared (Table 12). Table 12 includes the estimated probability of success and the probability standard error (estimate of the standard deviation of the population distribution), which was calculated using the equation

$$SE = \sqrt{\frac{p(1-p)}{n}}. \tag{6}$$

In Equation 6, $p$ represents the estimated probability of mission success and $n$ is the number of simulated battles.

Table 12. Base Case: P(Success) by Load Type and Body Armor Level.

| | Assault Load | | Fighting Load | |
|---|---|---|---|---|
| Body Armor Level | P(Success) | SE P(Success) | P(Success) | SE P(Success) |
| II | 0.615 | 0.0109 | 0.740 | 0.0098 |
| III | 0.632 | 0.0108 | 0.747 | 0.0097 |
| IV | 0.599 | 0.0110 | 0.695 | 0.0103 |

In order to determine if the differences in probability of success are significantly different, statistically, further tests and analysis were conducted. Hypothesis tests, using Fisher's exact test, were conducted for determining if the difference between each pair of success probabilities is statistically significant. The results are shown in Table 13.

Table 13. Base Case: Comparison of P(Success) Differences by Load Type and Body Armor Level.

| | **Fisher's Exact Test P-Value** | | |
|---|---|---|---|
| **Load Type** | **II and III** | **II and IV** | **III and IV** |
| Assault Load | 0.2815 | 0.3003 | 0.03195 |
| Fighting Load | 0.6124 | 0.001996 | 0.0002802 |

The statistically significant differences, using a significance level of 0.05, are highlighted in yellow. For both load types, there is no significant difference between body armor levels II and III. Therefore, it cannot be statistically concluded that the probability of success is higher for level III than level II. The data does show that the fighting load with either level II or III body armor increases the probability of success when compared to level IV. For the assault load, only the level III and IV probability comparison is significantly different.

In order to capture the effect of reduced hit probabilities on casualties, a Red P(H) Multiplier was added to the base case DOE. Blue casualty results are shown in Figure 20.

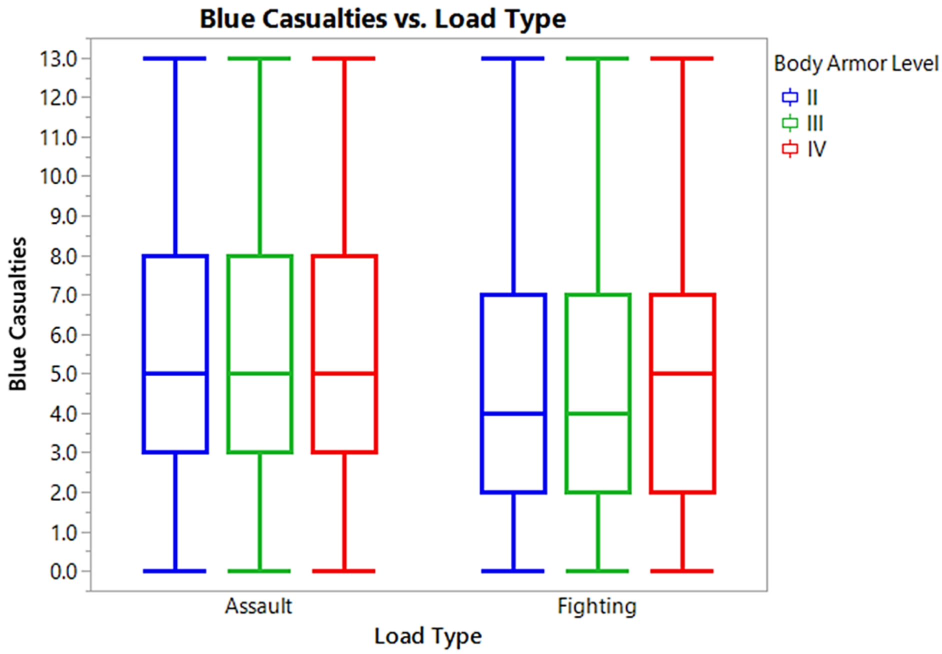



Figure 20. Base Case With P(H) Multiplier: Blue Casualties Boxplots by Load Type and Body Armor Level.

As expected, the median and interquartile range for each group shifted significantly due to the reduced probability of hit values introduced. The boxplot statistics for each group are displayed in Table 14. Similar to the base case, there is a difference of one casualty between the fighting load and the assault load for almost every group.

Table 14. Base Case With P(H) Multiplier: Blue Casualties Boxplots Statistics.

| | Blue Casualties | | | | | |
|---|---|---|---|---|---|---|
| | Assault Load | | | Fighting Load | | |
| Body Armor Level | Q1 | Median | Q3 | Q1 | Median | Q3 |
| II | 3 | 5 | 8 | 2 | 4 | 7 |
| III | 3 | 5 | 8 | 2 | 4 | 7 |
| IV | 3 | 5 | 8 | 2 | 5 | 7 |

To see how the reduced hit probabilities affected casualties between the two load types regardless of body armor level, the average number of casualties was calculated for each design point. The results were then grouped by load type and plotted (Figure 21).

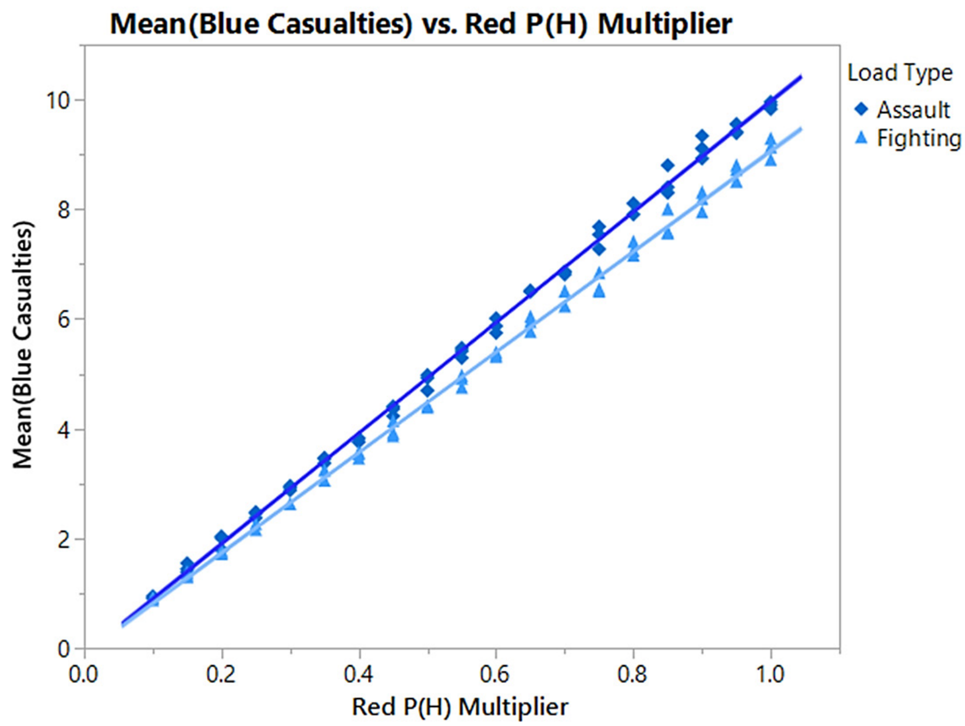



Figure 21. Base Case with P(H) Multiplier: Average Blue Casualties by P(H) Multiplier and Load Type.

Linear regressions were calculated for each load type, which are illustrated on the plot. The two regression lines diverge more significantly as the hit probability approaches that of a stationary target (1.0). This suggests that the weight difference between the fighting and assault loads has a greater effect on casualties as the probability of hit increases. Therefore, the heavier weight of the assault load, which reduces the speed of the Blue agents, increases the number of expected casualties when they are easier targets to hit.

To determine the point at which the Red P(H) Multiplier has the greatest impact on expected casualties, regardless of load type and body armor level, a partition tree was made

(Figure 22). The split point that resulted in the greatest difference in expected casualties is at 0.6, underlined in red.

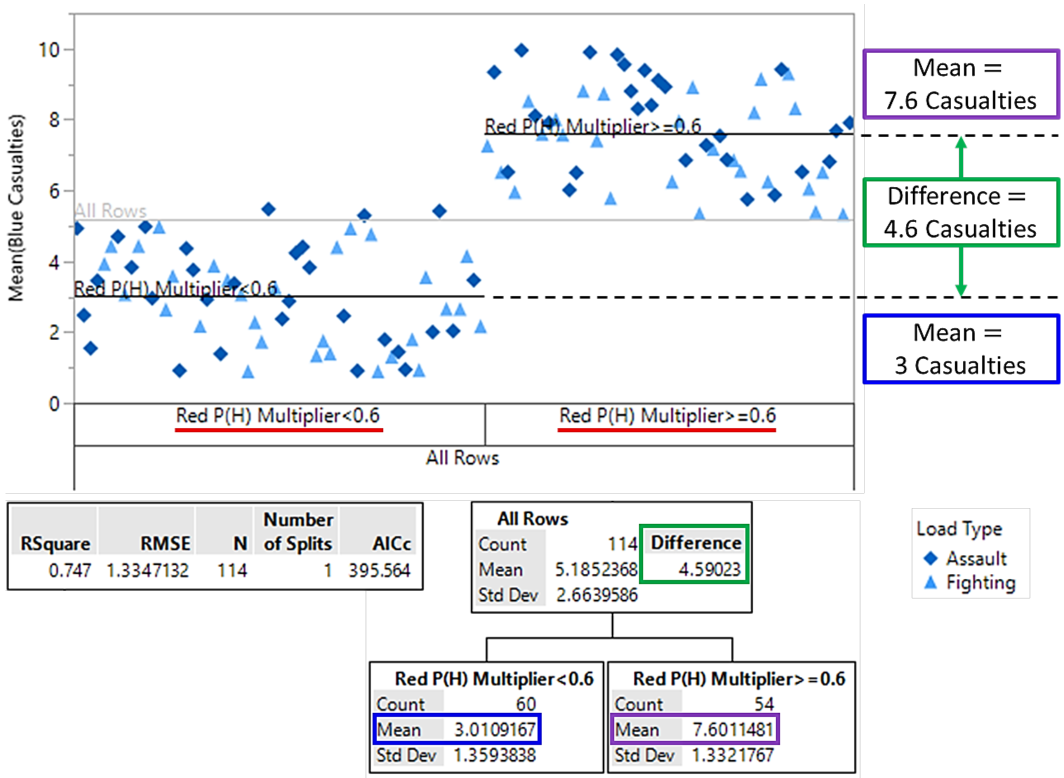



Figure 22. Base Case with P(H) Multiplier: Partition Tree for Expected Casualties.

The expected number of casualties is 7.6, outlined in purple, when the Red P(H) Multiplier is greater than or equal to 0.6. When it is less than 0.6, the expected number of casualties drops to three, outlined in blue. Thus, when wearing the fighting or assault loads, which have a weight range of 43 to 80 pounds, reducing a Marine's probability of being hit by 40 percent significantly decreases the number of expected casualties. In this thesis scenario, the number of casualties was reduced by 60 percent.

## C. EXTERNAL LOAD AND P(H) ANALYSIS AND RESULTS

As previously discussed, commanders are given the flexibility to alter the combat load based on their knowledge of the operational environment and the mission assigned.

To explore the effects of a wide range of external load weights and probability of hit values on casualties, the average number of casualties for each design point was computed—from 1,000 simulated battles per design point—and used as a basis for the analysis. Results from Experiment 1 illustrated the impact of the Red P(H) Multiplier on casualties changed based on weight (Figure 21). To see if there was a similar effect on the results from Experiment 2, which has a wider range of external load weights compared to Experiment 1, a scatterplot of the results was produced and is shown in Figure 23.

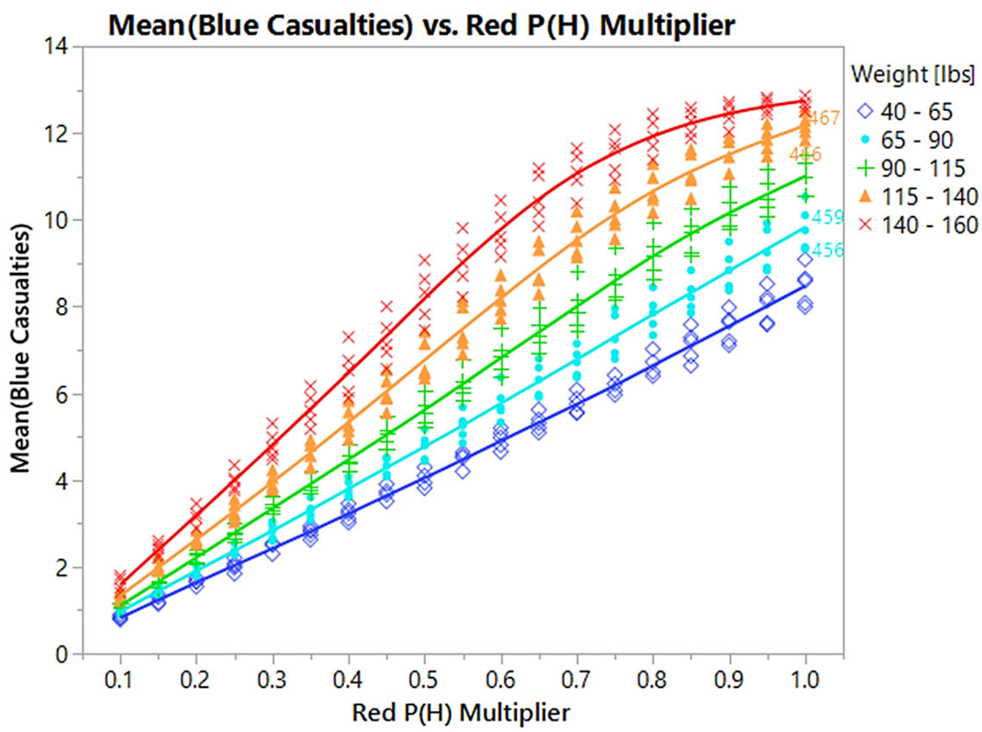



Figure 23. External Load and P(H) Analysis: Average Blue Casualties by Red P(H) Multiplier and Weight.

The External Load factor was broken down into weight groups, each having a range of 25 pounds, except for the heaviest group, which was 20 pounds. Similar to the results from Experiment 1, as the probability of hitting a target becomes more certain, the amount of weight carried has a more prevalent effect on the number of casualties suffered. This is shown by the increasing distance between the lowest (blue diamond) and heavier weight groups (Figure 23). Additionally, regardless of Red P(H) Multiplier, decreasing external load weight consistently decreased the number of expected casualties.

To see the point at which the probability of hit made the largest difference in Blue casualties, a partition tree was created (Figure 24). The split point occurs at a Red P(H) Multiplier equal to 0.55, resulting in a difference of about five casualties, outlined in blue.

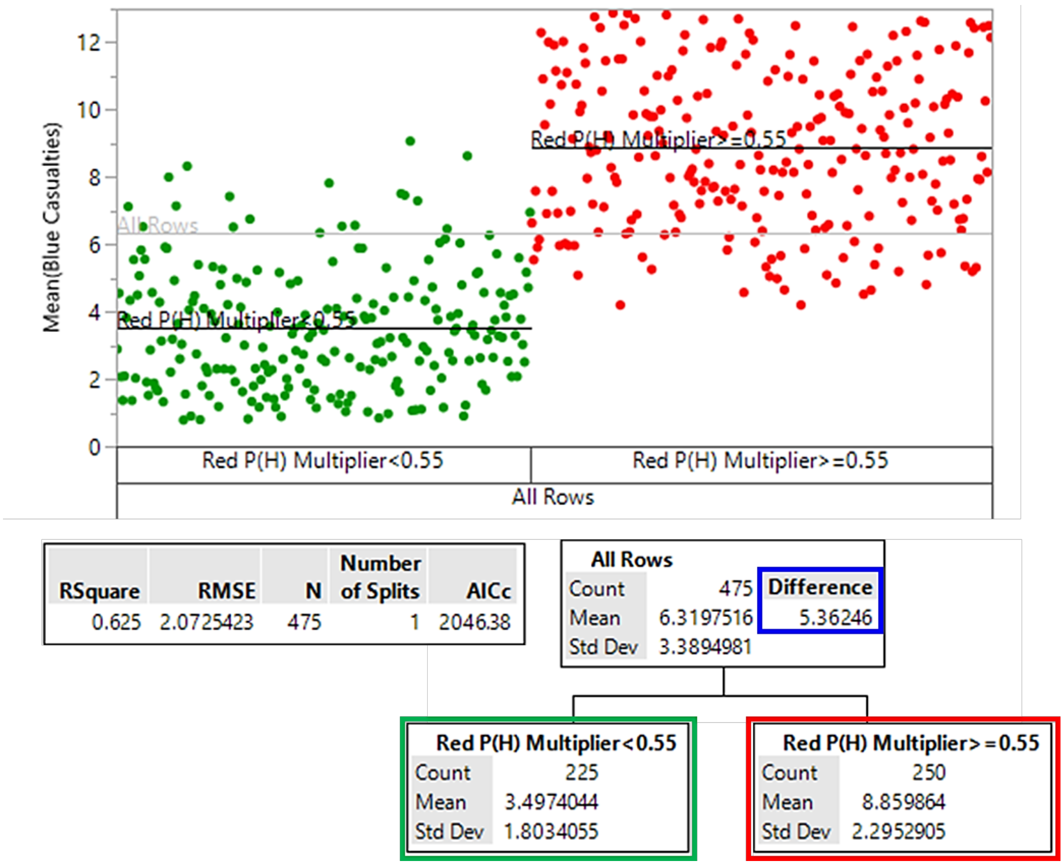



Figure 24. External Load and P(H) Analysis: Partition Tree for Expected Casualties.

There are two ways to interpret the split most beneficial to the Blue agents, where the Red P(H) Multiplier is less than 0.55. One is that the probability of hitting a stationary target—the P(H) from AMSAA—is less than 0.55 times that of a moving target. The other, and more intuitive, way is that the probability of hitting a moving target ($P_{move}$) is at least 1.8

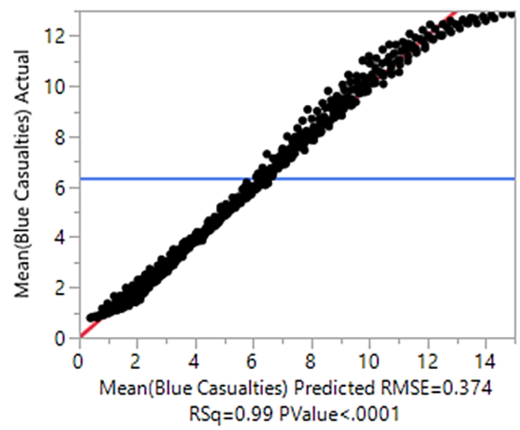
times as hard as hitting a stationary one ($P_{still}$). Both of these interpretations are equivalent through algebraic manipulation and are shown by

$$P_{still} < 0.55 P_{move} \rightarrow P_{move} \geq 1.8 P_{still}. \qquad (7)$$

For the thesis scenario, if the probability of hitting a moving target was roughly twice as hard as hitting a stationary one, then the expected number of Marine casualties dropped by about five (from 8.9 to 3.5)—almost 40 percent of the squad's manpower. On the other hand, if the probability of hitting a moving Blue agent was less than 1.8 times as hard as a stationary agent, then the expected number of casualties approached nine. Of note, subsequent splits also used the Red P(H) Multiplier factor, which revealed its dominance with respect to the outcome of the response.

Another way to explore relationships between the factors and the response is to fit a regression model. Ideally, a model is not overfit to the data and is as simple as possible while still producing accurate estimates. In this case, simple means that any factor interactions can be understood in the context of their effect on the response. Before making a model for the results from Experiment 2, it was known that the Red P(H) Multiplier factor would likely dominate in significance, due to its influence when creating the partition tree. Before the final model was produced (Figure 25), a model was made to explore possible polynomial effects; these were found to be significantly less important relative to the other factors; therefore, they were omitted.

**Actual by Predicted Plot**




**Summary of Fit**

| | |
|---|---|
| RSquare | 0.987903 |
| RSquare Adj | 0.987826 |
| Root Mean Square Error | 0.373988 |
| Mean of Response | 6.319752 |
| Observations (or Sum Wgts) | 475 |

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | -3.550087 | 0.061214 | -57.99 | <.0001* |
| Weight [lbs] | 0.0376096 | 0.000476 | 79.02 | <.0001* |
| Red P(H) Multiplier | 11.107054 | 0.062659 | 177.26 | <.0001* |
| (Weight [lbs]-100)*(Red P(H) Multiplier-0.55) | 0.0490418 | 0.001738 | 28.22 | <.0001* |

Figure 25. External Load and P(H) Analysis: Linear Regression Model for Estimating Blue Casualties.

The linear regression model has a high adjusted $R^2$ value, outlined in red, which is a representation of model fit that includes a penalty for the number of predictors used, with simpler models being penalized less. This penalization is done to prevent analysts from overfitting their models. The closer the adjusted $R^2$ value is to 1.0, the more variation in the data that is explained by the linear regression. Excluding the intercept, the significant predictors used in this model, outlined in blue, are the Red P(H) Multiplier, Weight, and the interaction between the two. The interaction term means that the effect of one factor (Red P(H) Multiplier) on the response (Blue casualties) depends on the value of the other factor it interacts with (Weight). The factor coefficients, listed under the "Estimate" column in Figure 25, describe the approximate effect each factor has on the response. For example, for every pound of weight carried, the expected number of Blue casualties increases by 0.0376. The interaction effect is displayed by the interaction profiles, with the slope of the line changing depending on the values of each factor (Figure 26). This was seen earlier in Figure 23, where the Red P(H) Multiplier has a greater effect on casualties for heavier weight groups.

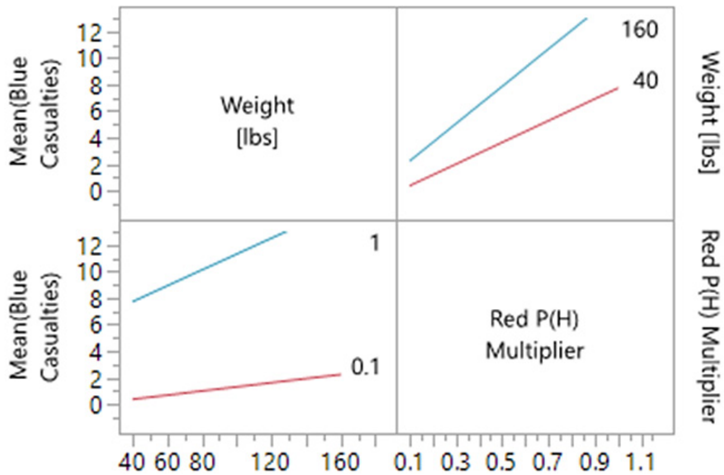
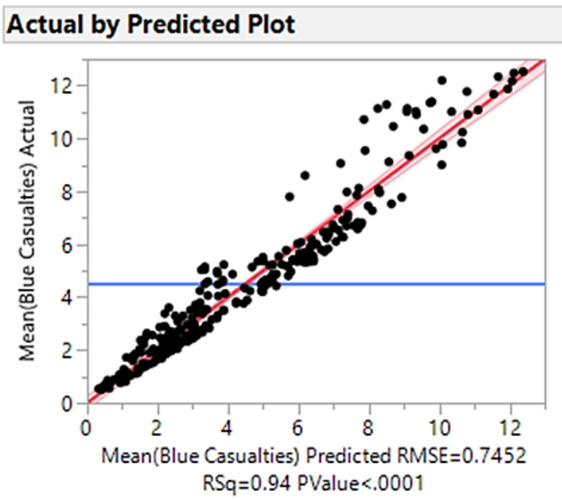



Figure 26. External Load and P(H) Analysis: Linear Regression Model Interaction Profiles.

## D. SPEED, PRONE TIME, AND P(H) SENSITIVITY ANALYSIS AND RESULTS

To understand how sensitive the simulation results were to specific factors, an experiment was done using a wide range of possible input values for each factor. The factors varied for analysis were a Blue agent's running speed (default state speed), the time a Blue agent spent in the prone firing position (reach waypoint state duration), and the Red P(H) Multiplier. Recall from Chapter IV.B that the Blue agents' speed varied from 0.5 to 2.5 meters per second, the prone time ranged from 5 to 30 seconds, and the Red P(H) Multiplier factor spanned from 0.1 to 1.0.

To explore the significance of all three factors with respect to the response, a first-order linear regression model with all possible two-way interactions was generated (Figure 27). Based on the p-values shown in the effect summary, outlined in blue, the only three significant predictors are the Red P(H) Multiplier, Blue agent speed, and the interaction between the two. A p-value is designated as significant if its value is below a chosen alpha ($\alpha$), which in this thesis is 0.05. All prediction terms that include the time spent in the prone position are not significant, as indicated by their high p-values outlined in green.




**Summary of Fit**

| | |
|---|---|
| RSquare | 0.93654 |
| RSquare Adj | 0.93519 |
| Root Mean Square Error | 0.745204 |
| Mean of Response | 4.537696 |
| Observations (or Sum Wgts) | 289 |

**Effect Summary**

| Source | PValue |
|---|---|
| Red P(H) Multiplier | 0.00000 |
| Speed [m/s] | 0.00000 |
| Speed [m/s]*Red P(H) Multiplier | 0.00000 |
| Prone Time [sec] | 0.51924 |
| Speed [m/s]*Prone Time [sec] | 0.72079 |
| Prone Time [sec]*Red P(H) Multiplier | 0.79375 |

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 4.0710669 | 0.179614 | 22.67 | <.0001* |
| Speed [m/s] | -2.631976 | 0.072814 | -36.15 | <.0001* |
| Prone Time [sec] | -0.003758 | 0.005823 | -0.65 | 0.5192 |
| Red P(H) Multiplier | 8.1668792 | 0.161516 | 50.56 | <.0001* |
| (Speed [m/s]-1.50623)*(Prone Time [sec]-17.5017) | 0.0037006 | 0.010344 | 0.36 | 0.7208 |
| (Speed [m/s]-1.50623)*(Red P(H) Multiplier-0.55031) | -4.559432 | 0.274267 | -16.62 | <.0001* |
| (Prone Time [sec]-17.5017)*(Red P(H) Multiplier-0.55031) | -0.006271 | 0.023963 | -0.26 | 0.7938 |

Figure 27. Sensitivity Analysis: First Order Linear Regression Model with Two-Way Interactions Summary.

Excluding the intercept, the significant predictors in this model are Speed, Red P(H) Multiplier, and the interaction between the two. The Speed factor coefficient, under the "Estimate" column, shows that increasing speed by one meter per second (2.2 mph) decreases the expected number of Blue casualties by about 2.63.

To see how the interaction between the Red P(H) Multiplier and Blue agent speed affected the expected number of Blue casualties, the interaction profiles were generated (Figure 28). When the Red P(H) Multiplier is varied, there is a significant change in slope based on a given speed (blue box), and vice versa (red box).

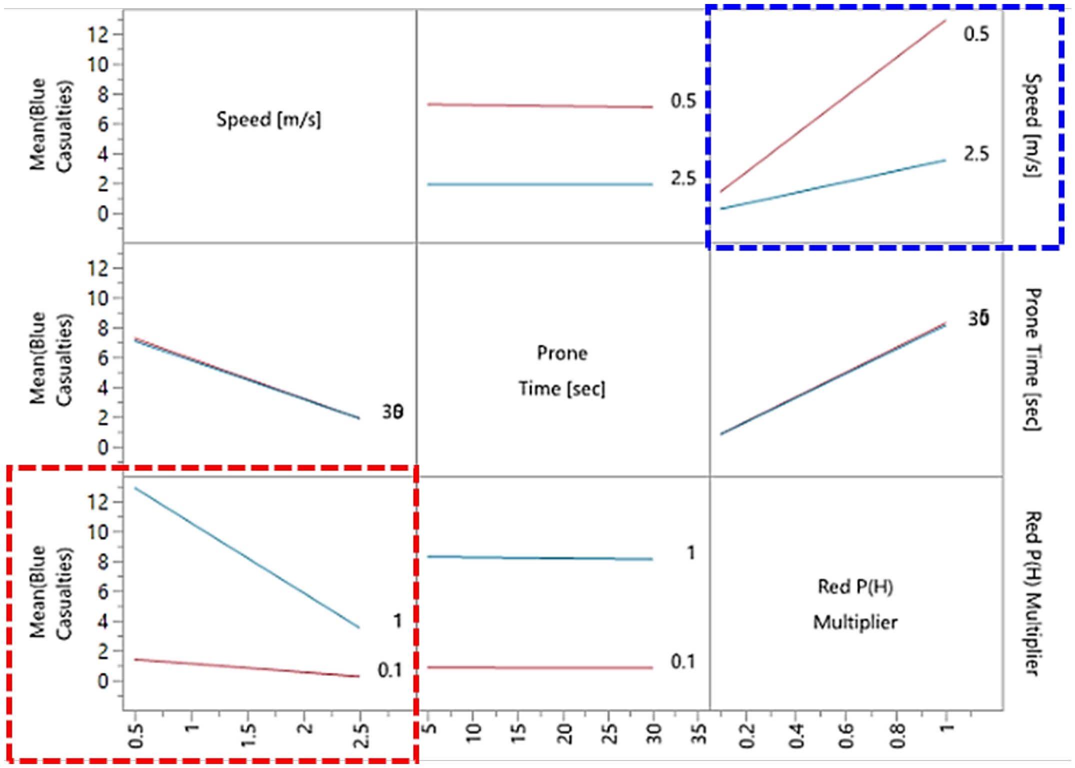



Figure 28. Sensitivity Analysis: First Order Linear Regression Model with Two-Way Interactions Interaction Profiles.

One way to interpret the interaction is when a Marine is easier to hit or the enemy fighter is an expert marksman, resulting in a high Red P(H) Multiplier, all the enemy needs is the opportunity (time) to shoot. Since a Marine's running speed determines how much time the enemy has to shoot at them in their most vulnerable state, presenting the largest target area, their speed has a significant effect on the expected number of casualties; the slower their speed, the more time the enemy has to take an accurate shot. Similarly, if an enemy fighter is a terrible marksman, a Marine's speed has less of an effect on the expected number of casualties, since the probability they will be hit during their six-meter bound is very low. The interaction profile shows the time spent in the prone firing position had a negligible effect on Blue casualties, shown by the nearly horizontal slope. This suggests that the results from Experiments 1 and 2 were likely not affected by the 15 second prone time model assumption.

To see if prone time affected the number of Red casualties, since the Blue agents are firing in the prone position, the average number of Red casualties was plotted against prone time (Figure 29). The horizontal slope of the regression line shows that the time spent in the prone firing position also has a negligible effect on Red casualties. This was surprising, but can perhaps be explained. One explanation is rooted in the fact that there are only four enemy agents to shoot at. With the current average number incapacitated slightly above three, more enemy agents may result in a larger spread in Red casualties. Another possible explanation is that the time spent firing may not have affected Red agents in the form of casualties as much as it affected the suppression of them. Unfortunately, the time a Red agent spent suppressed (in the shot at state) is not captured in the model output, so this possible explanation could not be investigated further.

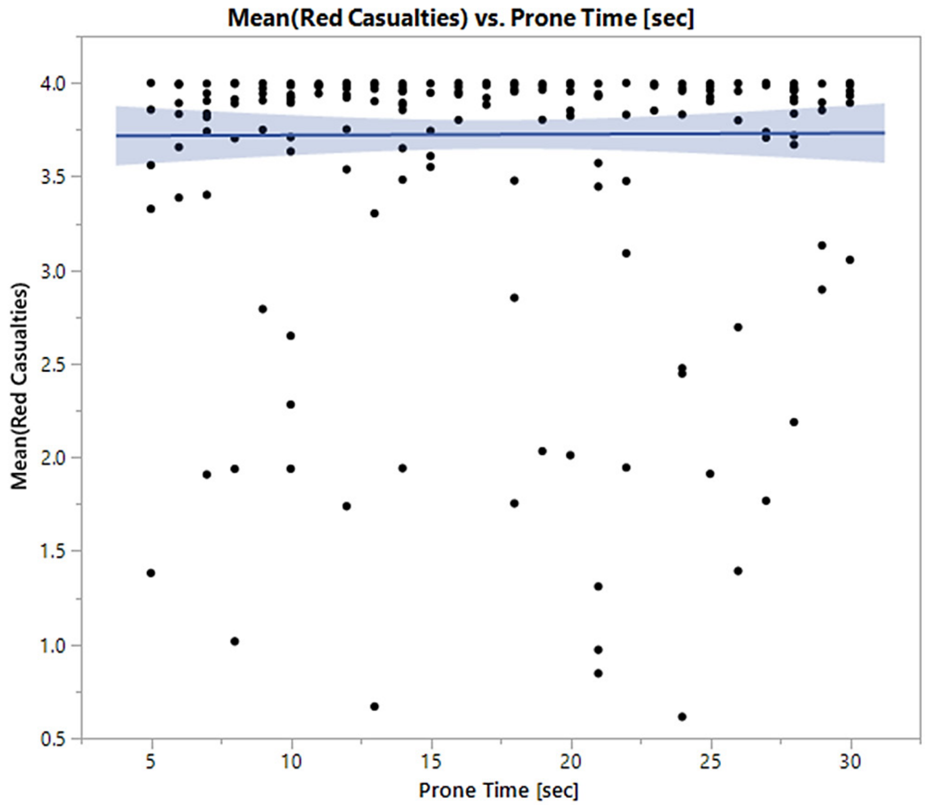



Figure 29. Sensitivity Analysis: Average Red Casualties by Prone Time.

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# VI. CONCLUSION AND FUTURE RESEARCH

> Individual loads on infantry personnel far exceed established standards, which negatively impacts the infantry squad's mobility, survivability, and lethality.
>
> — *Directive-Type Memorandum (DTM)-18-001: Establishment of the Close Combat Lethality Task Force (CCLTF)*

This thesis explored the effect of combat load weight on casualties and mission success for a Marine rifle squad in a highly exposed environment. Incorporating the results from human-subject research and current infantry Marines' marksmanship and physical fitness, the thesis model was able to capture effects of various loads and PPE configurations. Using multiple DOEs and data analysis techniques, the results from the experiments conducted will help commanders gain a greater understanding of how the combat load can both enhance and diminish the effectiveness and survivability of the warfighter.

The purpose of this thesis was to see if, for a scenario in which foot-mobile infantry Marines are highly exposed, increasing the combat load has an effect on the number of casualties and the probability of mission accomplishment. This thesis is not attempting to predict the number of casualties in battle or exact probabilities. Any difference in casualties or probability of mission success only indicates a trend, not a precise estimate. This model did not incorporate the effects of load-bearing fatigue on a Marine's ability to accurately and precisely engage the enemy, which could also have a significant effect on a battle's outcome.

## A. FINDINGS

Based on the model output from each experiment and subsequent data analysis, there were several important findings. These findings were separated into two categories: (1) standard loads and (2) movement speed and weight.

### 1. Standard Loads

Comparing the expected casualties between the fighting load and the assault load, there is a clear trend of an increase in casualties due to added weight. The data shows that the increase in 15 pounds from the fighting to the assault load, regardless of body armor level, increases the expected casualties by about one Marine in this squad-level engagement. This implies that the reduction in speed from carrying an extra 15 pounds of gear, when starting at a weight of at least 43 pounds, increases the amount of time exposed to enemy fire enough to result in an additional casualty.

The optimal load configuration, in terms of mission success, was achieved using the lightest standard load with the greatest level of protection for the enemy threat. For the thesis scenario, this was the fighting load with NIJ body armor level III. This was not a surprising result considering a common-sense solution is to have the maximum protection at the lowest possible weight. This conclusion supports the current policy of allowing commanders in the field to determine the appropriate PPE configuration based on the operational environment.

### 2. Movement Speed and Weight

When the P(H) multiplier factor is applied to capture the effects of a Marine being harder to hit, either by their movement speed or direction relative to the enemy, this alone significantly increases a Marine's probability of survival. When each Marine is roughly twice as hard to hit as a stationary target, there is a substantial decrease in expected squad casualties (from 8.9 to 3.5), which also increases the probability of accomplishing the mission. In reality, it is not unreasonable to imagine a moving target being twice as hard to hit as a stationary one. Based on target distance and speed, the shooter must properly lead their target to hit it. If it takes an enemy fighter at least two shots to hit a moving target, assuming they hit a stationary one with their first shot, then the number of casualties in a firefight is expected to decrease significantly.

As the external load carried increases in weight, the speed at which a Marine is able to run decreases, extending the time they are exposed to enemy fire while running. This increase in exposure time results in a more significant increase in casualties when the P(H) multiplier factor is high, compared to when the factor is low. In theory, a faster target is harder to hit and therefore should be associated with a lower P(H) multiplier, whereas a slower target should be associated with a higher P(H) multiplier (closer to that of a stationary target). Since this thesis did not make this association, due to a lack of data on the subject, the results represent a conservative estimation of the difference in expected casualties for various external load weights.

Regardless of the value of the P(H) multiplier, the data shows that decreasing weight decreases the number of expected casualties in the thesis scenario. This demonstrates that commanders and operational planners may be able to decrease the probability of their Marines becoming casualties by minimizing the required gear to be carried on missions. Although risk can never be eliminated from war, by obtaining a greater understanding of load's effect on a Marine's physical performance, commanders can more accurately weigh the risk and reward of adding a piece of gear for the capability it provides and cost of carrying it.

## B. CONCLUSION AND RECOMMENDATIONS

> Battles are won by slaughter and maneuver. The greater the general, the more he contributes in maneuver, the less he demands in slaughter.
>
> — *Winston Churchill*

Leaders in both the Marine Corps and the Army acknowledge the fact that current loads are excessive. Several recent initiatives have been pushed focusing on the reduction of weight carried into combat. The Marine Corps and the Army are looking to reduce the weight of PPE, which will help decrease the weight carried (GAO 2017). Additionally, former Secretary of Defense James Mattis released a Directive-type Memorandum (DTM) in 2018 establishing a Close Combat Lethality Task Force (CCLTF), which emphasizes the reduction of infantry loads (Secretary of Defense 2018).

Most of the weight carried into combat in recent wars was not from PPE, but from additional gear deemed mission-essential. Although a reduction in PPE will reduce the weight carried, it is not the primary source of the burden; therefore, leaders must not limit themselves to the solution of lighter PPE. A holistic approach to weight reduction must be taken, including reducing the gear carried for missions (scrutinizing what is mission-essential), examining currently fielded gear for weight reduction (e.g., radios), and identifying weight as a critical technical parameter for assessing new gear as part of the Survivability and/or Force Protection key performance parameters in DoD acquisitions. Another avenue of approach is to look at reducing the weight of current items using new material. For example, the Marine Corps is looking at replacing current aluminum magazines and brass-cased ammunition with polymer magazines and polymer-cased ammunition to lighten the warfighter's load (Military.com 2017).

The results from 885,000 simulated battles provides evidence that the reduction in speed caused by excessive weight increases the probability a warfighter becomes a casualty. The exact point at which the weight becomes excessive is undetermined. For the thesis scenario, an increase of at least one casualty is first seen in the base case when switching from the fighting load (43 pounds) to the assault load (58 pounds), both equipped with NIJ body armor level II. This demonstrates that loads approaching 60 pounds have an impact on casualties. Research has also shown that significant physical and marksmanship performance decrements occur when weights approach 45 percent body weight (Jaworski et al. 2015). Based on 2018 Marine Corps infantry demographics, this would amount to a weight between 74 and 78 pounds for an infantry Marine (Table 15).

Table 15. Body Weight and Combat Load Weight Comparison.

| Grade | Avg Weight [lbs] | 30% \| 45% Body Weight [lbs] |
|---|---|---|
| E1/2 | 164.4 | 49.3 \| 74.0 |
| E3 | 166.9 | 50.1 \| 75.1 |
| E4 | 170.1 | 51.0 \| 76.5 |
| E5 | 173.9 | 52.2 \| 78.3 |

| Body Armor Level | Fighting Load Weight [lbs] | Assault Load Weight [lbs] |
|---|---|---|
| II | 43 | 58 |
| III | 62 | 77 |
| IV | 65 | 80 |

Both S.L.A. Marshall (1980) and Jaworski et al. (2015) recommend a weight threshold of 30 percent body weight to maximize the warfighter's performance in combat. For the Marine infantry squad, this would amount to a range of 49 to 52 pounds (Table 15).

Based on the results of this thesis and previous human-subject research, the weight of a fighting load for infantry Marines and Soldiers should be as light as the mission allows, with a goal of under 50 pounds. This recommendation is consistent with several previous studies dating back to the late 1800s, which were summarized by Fish and Scharre (2018) in their report on combat load (Appendix D). Understanding that longer durations of sustainment require additional supplies and equipment, it is also recommended that a goal of under 75 pounds, approximately 45 percent body weight, be used for the assault load. Considering the current standard loads of the Marine Corps and the Army—which has an average fighting load of 60 – 80 pounds and approach march load of 80 – 100 pounds—both military branches would have to lighten these loads substantially to adhere to these weight recommendations (Department of the Army 2017). It is important to note that these weights will not be appropriate for all operational environments. These proposals are not meant to limit a commander's ability to properly equip their Marines or Soldiers with items essential to mission accomplishment.

Based on the future operating environment described in the MOC, Marines need leaders at all levels of the chain of command, now more than ever, to ensure their Marines are physically, mentally, and morally ready to fight our nation's battles in any clime and place. To be clear, this thesis is not diminishing the importance of physical training in preparation for combat. It is merely providing evidence of the fact that the human element of war brings with it human capabilities and limitations that affect survivability on the battlefield, commanders must acknowledge and plan for them accordingly. This means commanders need to ensure all gear required for the combat load are truly mission-essential and that none of the items were due to the commander's aversion to risk. Gear added for this purpose only shifts the risk from the commander to the warfighter; it does not eliminate the risk. By having a greater understanding of how Marines are affected by the decisions of leadership, specifically the physical weight placed upon their shoulders, the Marine Corps will become an even stronger, more effective fighting organization.

## C. AVENUES FOR IMPROVEMENT

### 1. Associate P(H) with Speed

A moving target is harder to hit than a stationary target. How much harder it is depends on many factors including, but not limited to, the target's speed, angle of movement, and distance from the shooter, as well as the shooter's skill. Since this data is unknown, the effects of a harder target to hit were generally captured by using a P(H) multiplier factor. In theory, the multiplier would be lower for faster-moving targets than slower-moving ones. For this thesis, specific speeds were not assigned P(H) multiplier values since the relationship between the two is unknown. If P(H) is associated with speed, the difference in expected casualties between lighter and heavier loads is expected to increase from what is estimated by this model. The resulting data could provide a greater understanding of weight's effect on casualties and possibly identify a weight threshold to not be exceeded.

### 2. Incorporate the Effect of Load-Bearing Fatigue on P(H)

When humans get fatigued, their ability to perform tasks decreases. Research has shown that fatigue compromises a Marine's ability to accurately and precisely fire at the enemy (Jaworski et al. 2015). Incorporating fatigue's effect on a Marine's probability of hitting the enemy would also increase the accuracy of the model.

## D. FUTURE RESEARCH

Several avenues for future research are proposed to further explore the impacts of combat load weight on the warfighter:

- In the MANA model, vary the distance the squad has to travel, the number of enemy fighters, and the terrain type (with cover and/or concealment).
- Incorporate the effect of weight-induced fatigue on marksmanship.
- Use a high-resolution simulation model, such as the Combined Arms Analysis Tool for the 21st Century (COMBATXXI) or Infantry Warrior Simulation (IWARS), to explore similar experiments with greater fidelity.
- Conduct field experiments to compare with the simulation results. Specifically, the T&R standard fighting load, T&R standard assault load, and GAO report 117-pound average combat load should be examined in

order to understand the true impact of weight carried on Marines (speed, fatigue, probability of being hit, etc.).

- Modify the model to simulate live fire testing done in the summer of 2018 conducted by The Marine Expeditionary Rifle Squad Team at Marine Corps Systems Command. This team looked at the probability of hitting moving targets at various speeds from distances of 100–300 meters.
- Explore the effects of load weight on non-combat (training) related injuries with respect to medical readiness in the fleet Marine force and medical separation and retirement rates.

This thesis has developed and demonstrated a methodology for taking multiple, individual-level human-subject research data and evaluating it in the context of a Marine mission (in this case with respect to casualties and mission success). This approach could be taken with additional human performance data and missions, perhaps of longer duration.

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# APPENDIX A. INFANTRY T&R LOADS

| Fighting Load | | | |
|---|---|---|---|
| Clothing Worn & Packed | Weight [lbs.] | Quantity | Total Weight [lbs.] |
| MCCU, Blouse and Trouser | 2.97 | 1 | 2.97 |
| Uniform, Utility, Belt | 0.3 | 1 | 0.3 |
| Ballistic Eye Pro | 0.31 | 1 | 0.31 |
| M50 Mask w/ carrier | 3 | 1 | 3 |
| Gloves | 0.3 | 1 | 0.3 |
| T-Shirt, Green | 0.18 | 1 | 0.18 |
| Undershorts | 0.25 | 1 | 0.25 |
| MC Combat Boots w/ laces | 3.12 | 1 | 3.12 |
| Socks | 0.16 | 1 | 0.16 |
| Watch, Wrist | 0.1 | 1 | 0.1 |
| Card, ID | 0.03 | 1 | 0.03 |
| Tags, ID | 0.1 | 1 | 0.1 |
| Helmet w/ cover, band, and NVG base plate | 3.5 | 1 | 3.5 |
| Plate Carrier w/ soft armor | 9 | 1 | 9 |
| SAPI Plates (front, back, and 2x side) | 19 | 1 | 19 |
| Pouches (1-dump, 3-magazine, 2 grenade) | 2 | 1/3/2 | 2 |
| IFAK - A1 First Aid Kit | 2.1 | 1 | 2.1 |
| AN/PVS-14 w/Elbow/Rhino Mount | 1 | 1 | 1 |
| Hydration System, CamelBak (Full) | 6.91 | 1 | 6.91 |
| **Total Fighting Load Weight (not including weapon, SL-3, and MOS-specific equipment)** | | | **54.33** |

**Note:** For MOS-specific Physical Standards purposes, when the Fighting Load is prescribed, each Marine will carry their assigned personal weapon (M4, M-16A4, or IAR) and appropriate SL-3 [seven (7) magazines (twenty-two (22) magazines for IAR w/ assault pack), combat assault sling, PEQ-15/16, RCO, Bayonet, weapons cleaning gear, and M203 or M32 (if assigned)].

| Assault Load | | | |
|---|---|---|---|
| Clothing Worn & Packed | Weight [lbs.] | Quantity | Total Weight [lbs.] |
| MCCU, Blouse and Trouser | 2.97 | 1 | 2.97 |
| Uniform, Utility, Belt | 0.3 | 1 | 0.3 |
| Ballistic Eye Pro | 0.31 | 1 | 0.31 |
| M50 Mask w/ carrier | 3 | 1 | 3 |
| Gloves | 0.3 | 1 | 0.3 |
| T-Shirt, Green | 0.18 | 1 | 0.18 |
| Undershorts | 0.25 | 1 | 0.25 |
| MC Combat Boots w/ laces | 3.12 | 1 | 3.12 |
| Socks | 0.16 | 1 | 0.16 |
| Watch, Wrist | 0.1 | 1 | 0.1 |
| Card, ID | 0.03 | 1 | 0.03 |
| Tags, ID | 0.1 | 1 | 0.1 |
| Helmet w/ cover, band, and NVG base plate | 3.5 | 1 | 3.5 |
| Plate Carrier w/ soft armor | 9 | 1 | 9 |
| SAPI Plates (front, back, and 2x side) | 19 | 1 | 19 |
| Pouches (1-dump, 3-magazine, 2 grenade) | 2 | 1/3/2 | 2 |
| IFAK - A1 First Aid Kit | 2.1 | 1 | 2.1 |
| AN/PVS-14 w/Elbow/Rhino Mount | 1 | 1 | 1 |
| Hydration System, CamelBak (Full) | 6.91 | 1 | 6.91 |
| Assault Pack | 5.51 | 1 | 5.51 |
| MRE | 1.3 | 3 | 3.9 |
| Parka and Trouser, APEC | 3.6 | 1 | 3.6 |
| Tool, Entrenching w/ Case | 2.7 | 1 | 2.7 |
| **Total Assault Load Weight (not including weapon, SL-3, and MOS-specific equipment)** | | | **70.04** |

**Note:** For MOS-specific Physical Standards Purposes, when the Assault Load is prescribed, the following additional equipment will be carried:

(a) MOS 0302 will carry: M4 w/ seven (7) magazines; combat assault sling; PEQ-15/16; RCO mounted; bayonet stowed; and cleaning gear.

(b) MOS 0311 will carry: either M-16a4, M4, or M27 (IAR) w/ seven (7) (twenty-two (22) for IAR) magazines; combat assault sling; PEQ-15/16; RCO; bayonet stowed; cleaning gear; and M203 or M32 (if assigned).

# APPENDIX B. LOAD CALCULATIONS

| COMBAT LOAD<br>(Reduced Assault Load) | | | |
|---|---|---|---|
| **Clothing Worn & Packed** | **Weight [lbs.]** | **Quantity** | **Total Weight [lbs.]** |
| MCCU, Blouse and Trouser | 2.97 | 1 | 2.97 |
| Uniform, Utility, Belt | 0.3 | 1 | 0.3 |
| Ballistic Eye Pro | 0.31 | 1 | 0.31 |
| M50 Mask w/ carrier | 3 | 1 | 3 |
| Gloves | 0.3 | 1 | 0.3 |
| T-Shirt, Green | 0.18 | 1 | 0.18 |
| Undershorts | 0.25 | 1 | 0.25 |
| MC Combat Boots w/ laces | 3.12 | 1 | 3.12 |
| Socks | 0.16 | 1 | 0.16 |
| Watch, Wrist | 0.1 | 1 | 0.1 |
| Card, ID | 0.03 | 1 | 0.03 |
| Tags, ID | 0.1 | 1 | 0.1 |
| Helmet w/ cover, band, and NVG base plate | 3.5 | 1 | 3.5 |
| Pouches (1-dump, 3-magazine, 2 grenade) | 2 | 1/3/2 | 2 |
| IFAK - A1 First Aid Kit | 2.1 | 1 | 2.1 |
| AN/PVS-14 w/Elbow/Rhino Mount | 1 | 1 | 1 |
| Hydration System, CamelBak (Full) | 6.91 | 1 | 6.91 |
| Assault Pack | 5.51 | 1 | 5.51 |
| MRE | 1.3 | 3 | 3.9 |
| Parka and Trouser, APEC | 3.6 | 1 | 3.6 |
| Tool, Entrenching w/ Case | 2.7 | 1 | 2.7 |
| M4 | 7.3 | 1 | 7.3 |
| **Total Combat Load Weight - Rifleman (w/o body armor, SL-3 and MOS-specific equipment)** | | | **49.34** |

| | NIJ Level II | NIJ Level III | NIJ Level IV |
|---|---|---|---|
| Body Armor Weight [lbs.] | 9 | 28 | 31 |
| Combat Load Weight [lbs.] | 49.34 | 49.34 | 49.34 |
| Ammunition Weight [lbs.] | 8 | 8 | 8 |
| **Total Assault Load Weight [lbs.]** | **66.34** | **85.34** | **88.34** |

**Note:** Ammunition weight based on seven full magazines of 5.56 mm rounds

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# APPENDIX C. BASE CASE ADDITIONAL TESTS

**Paired T-Test Results:**

Null Hypothesis: True difference in means is equal to 0

Alternative Hypothesis: True difference in means is not equal to 0

T-Statistic = 10.431, df = 2999, p-value < 2.2e-16

95% Confidence Interval: [0.6393321, 0.9353345]

Sample Mean Difference Estimate: 0.7873333

**Welch Two Sample T-Test Results:**

Same null and alternative hypotheses as paired t-test

T-Statistic = 10.306, df = 5996.1, p-value < 2.2e-16

95% Confidence Interval: [0.6375747, 0.9370920]

Mean Casualties (Load Type): Assault = 9.895333, Fighting = 9.108000

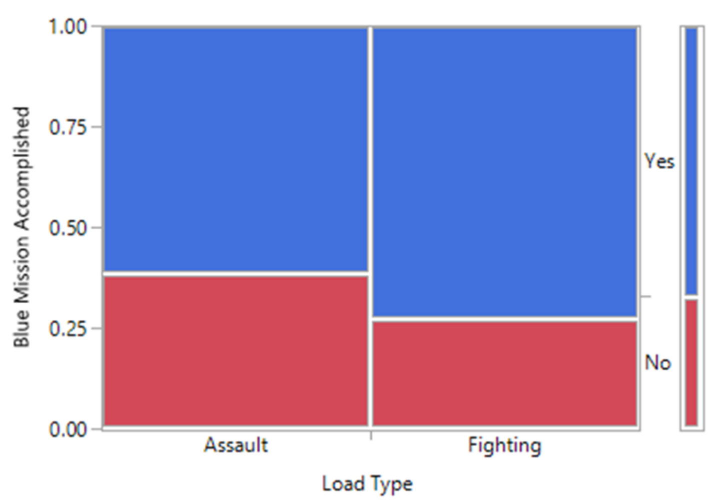
**Pairwise Comparisons Using Wilcoxon Rank Sum Test with Bonferroni Correction:**

| Adjusted P-Values for Pairwise Comparison | | | | | |
|---|---|---|---|---|---|
| | Assault II | Assault III | Assault IV | Fighting II | Fighting III |
| Assault III | 1.00 | - | - | - | - |
| Assault IV | 1.00 | 1.00 | - | - | - |
| Fighting II | 1.80E-07 | 4.40E-06 | 7.50E-09 | - | - |
| Fighting III | 5.90E-12 | 4.20E-10 | 1.10E-13 | 1.00 | - |
| Fighting IV | 8.60E-05 | 0.001 | 5.70E-06 | 1.00 | 0.079 |

| Weight Difference for Pairwise Comparison [lbs.] | | | | | |
|---|---|---|---|---|---|
| | Assault II | Assault III | Assault IV | Fighting II | Fighting III |
| Assault III | 19 | - | - | - | - |
| Assault IV | 22 | 3 | - | - | - |
| Fighting II | 15 | 34 | 37 | - | - |
| Fighting III | 4 | 15 | 18 | 19 | - |
| Fighting IV | 7 | 12 | 15 | 22 | 3 |

**Note**: Bonferroni correction used to maintain individual significance level of 0.05.

**Test for Difference in Probability of Mission Accomplishment Between Load Types:**




| | Mission Accomplished | |
|---|---|---|
| **Load Type** | Yes | No |
| Assault Load | 3691 | 2309 |
| Fighting Load | 4363 | 1637 |

| Fisher's Exact Test | Prob | Alternative Hypothesis |
|---|---|---|
| Left | 1.0000 | Prob(Blue Mission Accomplished=Yes) is greater for Load Type=Assault than Fighting |
| Right | <.0001* | Prob(Blue Mission Accomplished=Yes) is greater for Load Type=Fighting than Assault |
| 2-Tail | <.0001* | Prob(Blue Mission Accomplished=Yes) is different across Load Type |

# APPENDIX D. PAST FIGHTING LOAD RECOMMENDATIONS

| Recommendation by Source (in lbs) | | |
|---|---|---|
| Year | Recommending Body | Fighting Load (lbs) |
| Late 1800s | German William Frederick Studies | 48 |
| 1920s | Hygiene Advisory Committee of the British Army | 40-45 |
| 1930s | British Aldershot Committee | 35 |
| 1950 | U.S. Colonel SLA Marshall | 40 |
| 1990 | U.S. Army FM 21-18 | 48 |
| 2001 | U.S. Army Science Board Summer Study | 50 |
| 2003 | USMC Combat Load Report | 50.7 |
| 2007 | U.S. Naval Research Advisory Committee | 50 |

**Note:** Army FM 21-18 is now ATP 3-21.18, published in April 2017.

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