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Evaluating the Trade Space Between Individual Soldier Mobility and Survivability

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Author Note: Our capstone group consists of four students that attend the United States Military Academy. Cadets Angelo Natter and Andrew Wanovich are studying Engineering Management. Cadet Jacob Feuerman is studying Operations Research, while Cadet Donald Cochran is majoring in Systems and Decision Sciences. All four group members are scheduled to graduate with a Bachelor of Science in May of 2019.

Abstract: The purpose of this capstone project is to explore the trade space between individual Soldier mobility and survivability. Currently, Program Executive Office (PEO) Soldier, an organization responsible for the acquisition/integration of all individual Soldier equipment/weapons, is in the process of creating a performance model for an Army infantry rifle squad. They are interested in evaluating how Soldier mobility, survivability, and lethality influence the total value of a squad, which in turn will allow PEO Soldier to acquire and integrate the most useful equipment for Soldiers. Using Infantry Warrior Simulation (IWARS) and a linear regression model, this project quantifies survivability as a function of a calculated mobility score, the Soldier's operating environment, and a Soldier's equipment configuration.

Keywords: Modeling and Simulation, Linear Regression, Soldier Load

1. Overview

1.1 Introduction

The ability of a Soldier to move freely and without constraint in a combat scenario is essential for tactical effectiveness. Without the ability to move freely, an enemy can more easily pinpoint and destroy its target. The optimization of Soldier mobility, combined with the proper equipment load and protection, is imperative to maximizing their ability to survive, fight, and win on the battlefield.

1.2 Problem Statement

The purpose of this project is to explore and evaluate the trade space between a Soldier's mobility and survivability in an urban and open operating environment under a slick and full combat load equipment configuration.

1.3 Background

PEO Soldier, which falls under the Assistant Secretary of the Army (Acquisition, Logistics and Technology), has been tasked with developing a squad performance model. This model seeks to quantify, qualify, and combine elements of Soldier lethality, mobility, survivability to derive a squad lethality rating and measure overall combat effectiveness. Ideally, the output of this model will provide commanders with a better understanding of their formations, and how they can make their Soldiers more effective warriors.

While previous literature exists on Soldier mobility and survivability, this project aims to analyze how Soldier mobility, and survivability are affected by external factors: Soldier load, protection, and the operating environment. Our research effort supports Army Warfighting Challenge (AWFC) #9, which aims to "improve Soldier, leader, and team performance" (Army Warfighting Challenges, 2015). Understanding the trade space of Soldier mobility and survivability can better allow the U.S. Army to improve its doctrine, and in turn, give commanders more information about how to train and equip their formations to accomplish their missions.

2. Methodology

2.1 Defining Soldier Survivability and Mobility

The Joint Chiefs of Staff define survivability in the "DOD Dictionary of Military and Associated Terms" as "all aspects protecting personnel, weapons, and supplies while simultaneously deceiving the enemy" (The Joint Staff, 2019). Soldier mobility is the ability to effectively navigate obstacles on the battlefield in order to effectively accomplish the mission. In its essential components, Soldier mobility is a function of a (1) Soldier's demographics, to include their height, weight, and gender; (2) the Soldier's physical fitness levels; (3) the Soldier's carried and worn equipment, armor, and weapon systems; and (4) the physical environment that the Soldier is operating in. Each of these factors help determine a Soldier's ability to navigate the battlefield, combat the enemy, and survive a hostile engagement.

2.2 Developing the Functional Hierarchy

We developed a functional hierarchy (left half of Figure 1) to reflect the main elements necessary to understand the trade space between survivability and mobility. The four main functions of our functional hierarchy are physical fitness, Soldier demographics, the operating environment, and the equipment configuration. A Soldier's baseline mobility can be estimated through their demographics to include their height, weight, and gender, and by measuring their physical fitness, estimated using the Army Physical Fitness Test (APFT). In section 3.1, we describe how we create a linear regression model from these first two functions of our functional hierarchy to determine a mobility score. This mobility score can then be tested under various equipment configurations and operating environments within Infantry Warrior Simulation (IWARS) to determine the survivability of the Soldier (right half of Figure 1).

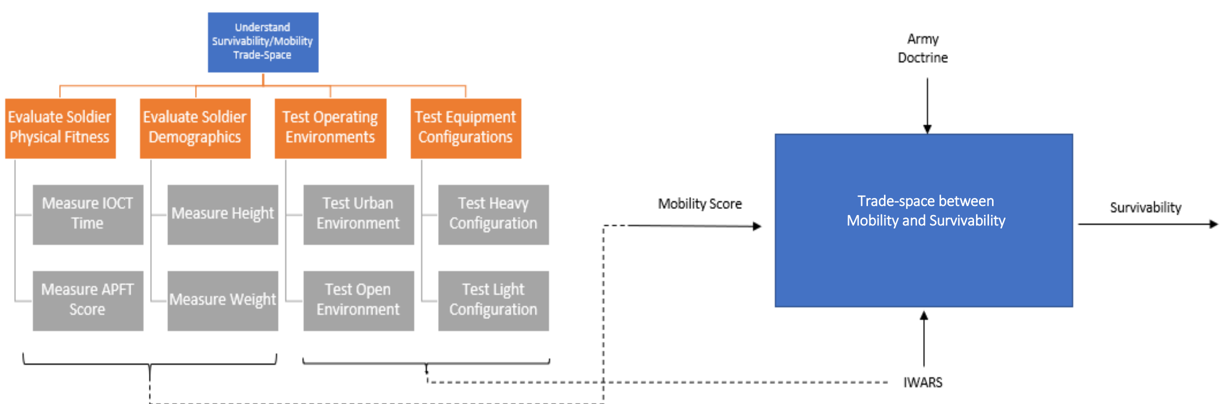

Figure 1. Connecting the Functional Hierarchy to the IDEF0 Model

2.3 Quantifying Mobility

The Indoor Obstacle Course Test (IOCT) is a West Point specific fitness test that evaluates full-body physical fitness. How well a Soldier navigates this course serves as a proxy for Soldier mobility. In addition to the fitness fundamentals that include aerobic and anaerobic cardiorespiratory endurance, muscular strength, muscular endurance, and flexibility, the timed events of the IOCT include the navigation under, over, through, and around multiple obstacles. The test is designed to emulate obstacles that may be found in an urban environment to include low walls and windows. Because of the nature of the IOCT and its practicality as an overall fitness test, this project uses a Soldiers' ability to navigate the course as a measure of how "mobile" they are with no load or equipment worn or carried.

2.4 Data Collection

The data for this project came from the United States Military Academy's G5 office, which stores each cadet's personal data. After completing an institutional review board (IRB) exception, de-identified data for 3,800 West Point cadets from the Class of 2018 through the Class of 2021 was provided. The data was cleaned, which resulted in the removal of approximately 350 cadet data entries. Of the remaining 3453 cadets, 725 were female and 2,738 were male. This data consisted of each cadet's raw scores for all of the APFT events of push-ups, sit-ups, and the two-mile run, as well as their IOCT times, height, weight, age, and gender.

2.5 Translating IOCT Time to Mobility Score

The IOCT times from the provided data were plotted and broken up into percentiles of ten. An IOCT time in the bottom tenth percentiles (slowest IOCT times) would be given a mobility score of one. Soldiers in the 90^{th} to 100^{th} percentile would have a mobility score of ten because they fall in the top ten percent of all scores. It is important to note that the scales are different for males and females (a mobility score of 10 for a male does not equal a 10 for a female). See Figures 2 and 3 below.

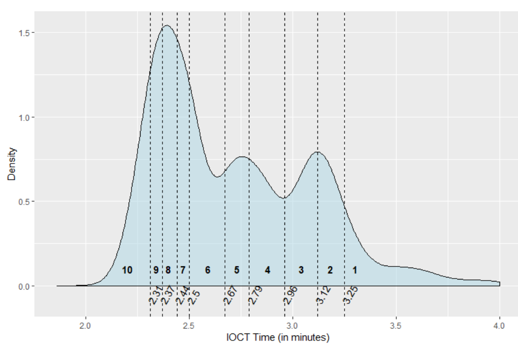

Figure 2. Male Mobility Quantiles

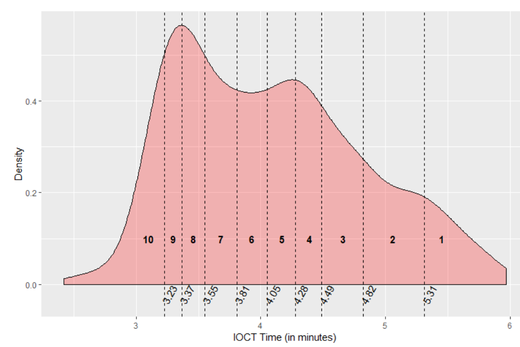

Figure 3. Female Mobility Quantiles

To calculate the rate of speed of each "slick" Soldier in IWARS, the median time within each tenth percentile is divided by the total distance covered by the IOCT (1,848 feet). The "full combat load" speed was adjusted from the "slick" speed using previous research which estimates the reduction of Soldier speed under load (Kewley, 2019). Additionally, in each tenth percentile of IOCT score, the height and weight of each Soldier was averaged and then used as the input for the IWARS trials. Table 1 and 2 shows these averages from each mobility score quantile.

Table 1. Male Scores (IWARS inputs)

Mobility Score	Height (inches)	Weight (pounds)	Speed (feet/second)
1	70.54	199.59	7.64
2	70.01	178.24	9.36
3	69.95	173	9.81
4	70.02	171.8	8.95
5	70.33	174.51	9.56
6	70.2	170.48	10.44
7	70.15	169.83	11.03
8	70.28	168.46	11.5
9	69.54	163.69	11.95
10	69.75	162.75	12.62

Table 2. Female Scores (IWARS inputs)

Mobility Score	Height (inches)	Weight (pounds)	Speed (feet/second)
1	65.4	149.11	5.06
2	65.53	145.1	5.77
3	65.06	138.75	6.04
4	65.74	145.04	6.64
5	65.15	138.68	7.17
6	65.07	135.65	7.11
7	65.01	138.11	7.44
8	64.92	136.79	8.2
9	65.43	134.7	8.79
10	65.28	133.67	9.52

2.6 Exploring Mobility Versus Survivability through Simulation

Army doctrine governs the movement techniques and battle drills that are programmed into IWARS. By testing gender specific team-sized elements configured to move at 10 unique speeds, in two different operating environments (open and urban), and two equipment configurations (slick and full combat load), we can quantify the trade space between mobility and survivability. The "slick" equipment configuration tests Soldiers with just a helmet and a weapon, while the "full combat load" configuration tests Soldiers with a helmet, weapon, body armor, and gear totaling 100 pounds. The 100-pound weight was chosen because a typical march load of worn and carried equipment fluctuates around 100 pounds according to a 1st BCT 82nd Airborne Division study (Task Force Devil Combined Arms Assessment Team, 2003). In these simulated scenarios, our simulation measures survivability based on the average percent of Soldiers killed in the engagement of each scenario after thirty runs. Plots for mobility and survivability for each gender can then be constructed based on the combination of the equipment configuration and operating environment.

3. Model: Predicting a Mobility Score

3.1 Linear Regression Model

Using the data from the IRB, we developed two linear regression models, one for males and one for females. These models predict IOCT time (a proxy for mobility), with predictors: height, weight, APFT push-ups, APFT sit-ups, and APFT 2-mile run. Before creating the regression model, the correlation between each predictor was visualized. See Figure 4. The individual predictors for the linear regression model almost all follow a normal distribution curve when plotted.

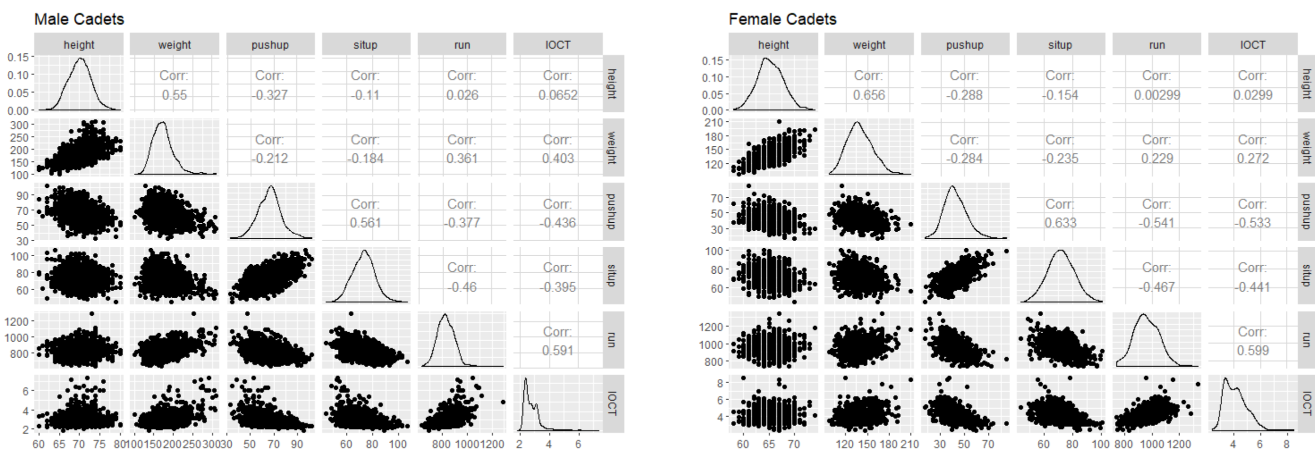

Figure 4. Pairs Plot for Males and Females

After ensuring that all multiple linear regression assumptions were met (linearity, homoscedasticity, and normality of residuals), the two regression models were created. A male's IOCT time can be calculated using the following:

$$\widehat{IOCT\ Time} = 3.50 - 0.042(height) + 0.0065(weight) - 0.015(pushups) - 0.0022(situps) + 0.0027(two\ mile\ run) \quad (1)$$

A female's IOCT time score can be calculated using the following:

$$\widehat{IOCT\ Time} = 5.72 - 0.073(height) + 0.0115(weight) - 0.027(pushups) - 0.0059(situps) + 0.0033(two\ mile\ run) \quad (2)$$

Tables 3 and 4 give a summary of the predictive power of the linear regression model:

3.2 Interpreting the Male and Female Mobility Regression Models

The coefficients of each model (see Figure 5) yield powerful conclusions about how demographics affect mobility for males and females, respectively.

Table 3. Male Model Statistics

Predictor	p-value
Intercept	< 2e-16
Height	< 2e-16
Weight	< 2e-16
Push-ups	< 2e-16
Sit-ups	0.0244
2-Mile Run	< 2e-16
Overall Model	
p-value	< 2e-16
Adj. R^2	0.4309
AIC	25099.91
BIC	25141.29

Table 4. Female Model Statistics

Predictor	p-value
Intercept	< 2e-16
Height	< 2e-16
Weight	< 2e-16
Push-ups	< 2e-16
Sit-ups	0.0753
2-Mile Run	< 2e-16
Overall Model	
p-value	< 2e-16
Adj. R^2	0.4409
AIC	7390.404
BIC	7422.507

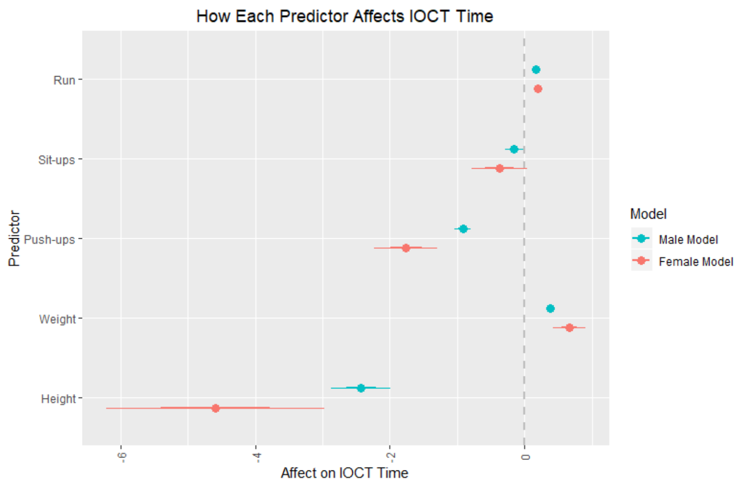

Figure 5. Coefficient Plot for each Model

The models reveal that two-mile run time, sit-ups, and weight cause little change in IOCT times. For females, however, an increased number in push-ups and an increase in height decrease their IOCT time more than in males. This reveals two conclusions about IOCT scores for females: having upper body strength and being taller decreases their IOCT time more than it does for males. This finding is intuitive because it is difficult for shorter females to climb objects, especially when they are limited by their upper body strength. The inhibiting factor for female Soldiers to navigate obstacles on the battlefield is their upper body strength. For males, the most limiting factor is their running ability.

4. Results

The mobility speeds from Tables 1 and 2 were used as inputs into IWARS. Each mobility speed was tested against each of the two operating environments (open and urban) and each equipment configuration (slick and full combat load). The results are shown in Figure 6.

The top two frames are female, four-person teams operating in the open and urban environments; the bottom two frames are the males. The colors represent the two different equipment configurations tested in the simulation: the full combat loadout (100 lbs.) and the slick loadout (just helmet and weapon). The x-axis is the mobility score tested, and the y-axis is the survivability percentage for that respective mobility level.

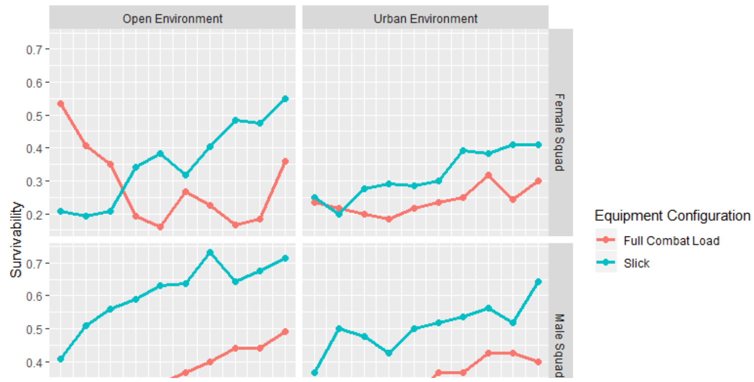

Figure 6. Male and Female Mobility vs. Survivability Score for both Operating Environments and Equipment Configurations

There are two general conclusions from the results of the simulation: survivability increases as mobility increases and the slick loadout maximizes survivability in most scenarios. The first conclusion holds true for nearly every scenario. However, there is a greater difference in survivability levels between the two configurations within male squads. Male squads survive at much higher rates when operating in the slick configuration. Females survive higher with a slick loadout when their mobility scores are higher than ~2-3. This concludes that female squads benefitted from more equipment (at the cost of slower speeds), until their speeds exceeded a mobility score of 2-3. Once they exceed those speeds, the benefit of the increased speed outweighs the benefit of more equipment. The results from the female team with a full combat load out in the open environment do not follow the expected trend as survivability decreases as the mobility score increases.

5. Future Work

Possible future work for this project can include transitioning this model from the retiring APFT to the new Army Combat Fitness Test (ACFT). The ACFT is proven to be a much better test of functional fitness and can significantly improve our prediction of a Soldier's mobility. This model rests on quite a few assumptions, including that the IOCT is an effective proxy of a Soldier's mobility. Additionally, our model considered only West Point Cadets' physical scores and demographics. Since Cadets at West Point are primarily between the ages of 18 and 23, our results may not translate to the Army as a whole. Perhaps, data should be compiled from a much more comprehensive list of Soldiers, including a wider age range. Additionally, a test to directly measure mobility should be designed, implemented, and tested within the Army. Hopefully, PEO Soldier can continue this work so that individual Soldier mobility is quantified, and the trade space is understood. This will allow their squad concept model to continue to empower leaders and commanders to build the most lethal, mobile, and survivable teams for the United States Army.

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