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Evaluating the Impact of Soldier Load on Mobility, Lethality, and Survivability

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Author Note: Cadets Andrews, Dorko, Parker, and Scott are members of West Point's Class of 2020 and conducted this year-long research project under the direction of LTC Hughes. Upon graduation, the cadets will commission into the U.S. Army as Second Lieutenants, serving in either Infantry or Air Defense Artillery. Our team would like to thank the West Point Simulation Center for providing access and support to the engagement skills trainer (EST) and Program Executive Office (PEO) Soldier for their help in providing and setting up the mobility course obstacles.

Abstract: Today's Army requires physically fit Soldiers that are mobile, lethal, and survivable. However, as technology continues to advance, the Army attempts to increase Soldiers' capabilities with additional equipment. These additional capabilities come at the cost of additional weight, which makes the Soldier less mobile and therefore less effective in terms of lethality and survivability. Understanding the trade space between mobility, lethality, and survivability better allows 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. With this in mind, this research aims to: (1) quantify mobility through linear regression models, (2) analyze the effect of increased load on a Soldier's lethality and mobility through a controlled study, and (3) simulate the effect that different mobility speeds have on a Soldier's survivability using Infantry Warrior Simulation (IWARS).

Keywords: Soldier Load, Mobility, Survivability, Lethality, Army Combat Fitness Test, Army Physical Fitness Test

1. Overview and Problem Statement

The purpose of this capstone project was to explore the trade space between individual Soldier mobility, lethality, and survivability. Our efforts assisted Program Executive Office (PEO) Soldier, an organization responsible for developing and fielding Soldier equipment, in creating a performance model for an Army infantry rifle squad. Their performance model will in turn influence what equipment PEO Soldier will design and integrate into the U.S. Army. To assist PEO Soldier, our project focused on three lines of effort (LOEs): (1) quantifying mobility, (2) understanding the trade space between mobility and lethality, and (3) understanding the trade space between mobility and survivability. These three LOEs directly addressed our problem statement, which is to understand the impact of a Soldier's load on mobility, lethality, and survivability.

2. Methodology

2.1 Line of Effort (LOE) Identification

Our research was comprised of three efforts. For the first effort, we used West Point's Indoor Obstacle Course Test (IOCT) as a proxy for mobility because it simulates many movements that would be expected of a Soldier in combat such as a low crawl, jumping over small walls, climbing over high walls, crossing a balance beam, and jumping through a window (Cochran et al., 2019). We then looked at data available in the Army, such as the Army Physical Fitness Test (APFT) and the new Army Combat Fitness Test (ACFT), to create a linear regression model that predicts a Soldier's mobility (IOCT time). Second, our research analyzed mobility and lethality through a controlled experiment where participants negotiated a mobility course followed by a shooting test on a simulated range. This controlled study sent 42 voluntary participants through our mobility course: once without additional weight, and once with approximately 35% of the participant's body weight in additional load (FM 21-18, 2017). Finally, we used mobility speeds from our controlled study to model the tradeoff between mobility and survivability via the Infantry Warrior Simulation (IWARS). IWARS enabled us to explore how different equipment loads affected the overall mobility speed and likelihood of survival for a squad-sized infantry element by using stochastic modeling. We developed two IWARS scenarios: one in an urban terrain setting and one in an open field terrain setting. We then ran different squad configurations with varying movement speeds and body armor in order to see the effect mobility has on survivability (Drain et al., 2012).

Figure 1 uses an IDEF0 Model to highlight our three LOEs. The three boxes indicate the function of each LOE. The arrows to the left of the boxes specify the inputs of each effort, the right most arrow shows the output(s) of each effort, the bottom arrows indicate the mechanism used to address each function/LOE, and the top arrow specifies any controls for each effort. It is important to note how the outputs from LOE 1 and LOE 2 become inputs to LOE 3.

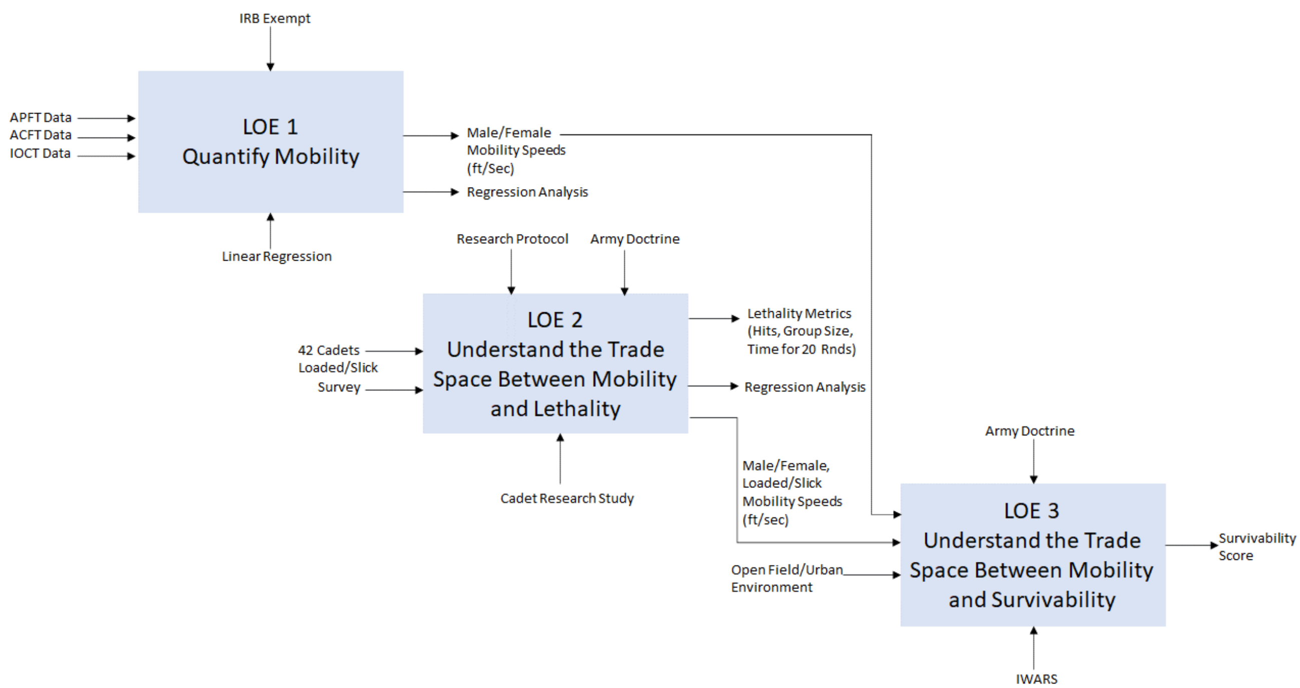

Figure 1. IDEF0 Model of Research

2.2 LOE 1: Quantify Mobility

In order to model how changes in mobility affect a Soldier's survivability and lethality, we first must quantify mobility. Building off last year's capstone work by Cochran et al., we believe that the IOCT is a good proxy for mobility because it simulates much of the mobility required of Soldiers in combat (2019). It includes jumping through a tire (which simulates climbing through a window), vaulting a low wall, climbing a high wall, running across a balance beam, and conducting a low crawl (Bishop et al., 1999). While the IOCT is arguably a good proxy for mobility, it is a test unique to West Point, and Soldiers outside of West Point are not able to run the course. Therefore, we created linear regression models to predict IOCT times and, ultimately, mobility speeds based on information that is available on every Soldier across the entire organization.

We created three separate linear models using demographic, APFT, and ACFT data as predictors of IOCT performance. The first model only used demographic information including a cadet's height, age, weight, and gender. The second model utilized the same demographic information, as well as the three events of the APFT (push-ups, sit-ups, and two-mile run). Given that the APFT is a limited measure of a person's physical fitness and knowing that the Army is replacing it with the ACFT, we also wanted to see how this new test could predict a cadet's IOCT time. The final model utilized the same demographic information as well as the data on all six ACFT events (hand release push-ups, 3 repetition maximum deadlift, leg-tucks, sprint-drag-carry, standing power throw, and the two-mile run). We then compared the models to see which best predicted IOCT times, which could then be converted to mobility speeds.

2.3 LOE 2: Understand the Trade Space Between Mobility and Lethality

Our group completed a full protocol with the Institutional Review Board (IRB) to get approval to run a controlled research study that measured the effects of Soldier load on their mobility and lethality. Before the participants could conduct the mobility course (MC) and fire on the engagement skills trainer (EST) range, they had to fill out a consent form and survey. This survey gathered information on the participants including demographic information, scores from their most recent APFT and ACFT, most recent IOCT time, and information on M4 qualification score/firing frequency. These de-identified surveys were linked to their performance on the mobility course and EST range in order to protect the privacy and confidentiality of participants. We received a total of 42 volunteers (33 males and 9 females), and each subject was currently participating on a West Point Sandhurst team. A Sandhurst team consists of cadets who actively conduct military training and compete in Soldier tasks and drills. We chose to test Sandhurst cadets because they most accurately represent an active duty, combat arms service member.

The controlled research study aimed to measure the effects of weight while negotiating obstacles followed by a lethality test in the EST. The mobility course featured six obstacles: a window climb, high wall, low wall, balance beam, six flights of stairs, and a low/high crawl. The lethality test required participants to fire two, 10-round magazines at a stationary target (simulated to be 175 meters away) from the kneeling position. We chose this test because it required participants to engage a target from a challenging shooting position and provided quantitative results (i.e. number of hits, shot group size, etc). Participants were required to run through the course twice: once slick (with rifle and kevlar) and once with an additional combat load of 35% of their body weight (additional load included the weight of rifle and kevlar). We used this percentage in accordance with the combat load described in the Army's Field Manual 21-18: Foot Marches (2017). In order to mitigate the learning effect, half the participants were randomly selected to run the slick iteration first and the other half started with the loaded iteration. Each participant had at least an hour break to recover between iterations. The study looked to see how load affected mobility by measuring the time to complete the first four obstacles, the time to complete the entire MC, and which (if any) obstacles a participant was unable to complete. The study then looked at the effect of load on lethality by measuring the number of targets hit, the shot group size (diameter of the smallest circle that encloses all 20 rounds fired), and the time it took to fire both 10-round magazines (Ito et al., 2003). Finally, similar to LOE 1, we did a regression analysis to see if mobility and lethality performance in the study could be predicted based upon the participants' survey results.

2.4 LOE 3: Understand the Trade Space Between Mobility and Survivability

Utilizing the results from the controlled research study, we created an IWARS simulation to analyze the tradeoff between the mobility and survivability of Soldiers. Initially, as seen in Figure 1, we intended to use the mobility speeds calculated from our IOCT data. However, we determined that these speeds were unrealistically fast for a Soldier operating in a new and unfamiliar environment. Instead, we used the average speed of participants during the first four obstacles of the MC as the speed for Soldiers in an urban terrain setting and the average speed of participants in the last two obstacles (stairs and low/high crawl) as the speed for Soldiers in an open field terrain setting (IWARS Methodology Guide, 2014). A summary of our mobility speeds is found in Table 1. Varying gender, load configuration, and environment yielded eight input mobility speeds for our IWARS model. We ran the 8 scenarios 50 times each and recorded the percentage of friendly Soldiers who survived each simulation run as a distribution.

Table 1. Summary of Input Mobility Speeds and How They Were Calculated

	Male					Female				
	LOE 1 (IOCT)	LOE 2 (First 4 Obstacles)		LOE 2 (Last Two Obstacles)		LOE 1 (IOCT)	LOE 2 (First 4 Obstacles)		LOE 2 (Last Two Obstacles)	
Distance Traveled [ft]	1848	87		357		1848	87		357	
Average Time of Completion [sec]	167	Loaded	Slick	Loaded	Slick	232	Loaded	Slick	Loaded	Slick
		57.3	29.9	120.5	82.7		97.3	45.8	152.7	104.2
Average Speed -IWARS Input [ft/sec]	11.1	Loaded	Slick	Loaded	Slick	8.0	Loaded	Slick	Loaded	Slick
		1.5	2.9	3.0	4.3		0.9	1.9	2.3	3.4

3. Results

3.1 LOE 1: Quantify Mobility

As we mentioned in Section 2.2, we developed three different linear regression models to predict IOCT time. To compare the models, we used adjusted r-squared and the Akaike information criterion (AIC), which is an estimator of the quality of each model relative to the others (lower AIC is better). The first, Equation 1, used demographic information including height, weight, age, and gender. This model achieved an adjusted r-squared value of 0.690 and an AIC of 6147. The second, Equation 2, used demographic and APFT scores resulting in an improved adjusted r-squared value of 0.795 and an AIC of 5841. The third, Equation 3, used demographic and ACFT scores. This ACFT model had an adjusted r-squared value of 0.793 and an AIC of 5864. Age was removed from all three models and deadlift was removed from the third model because they had no statistically significant predictive power. It was surprising that the new ACFT was not a better indicator of mobility than the old APFT given that it is a more comprehensive fitness test. The three models are shown below.

$$\widehat{IOCT\ Time} = 267.8 - 1.4(height) + 0.4(weight) - 74.8(genderM) \quad (1)$$

$$\widehat{IOCT\ Time} = 196.5 - 0.7(height) + 0.2(weight) - 51.5(genderM) - 0.4(PU) - 0.3(SU) + 0.1(TMR) \quad (2)$$

$$\widehat{IOCT\ Time} = 191.4 - 0.9(height) + 0.4(weight) - 45.3(genderM) - 0.4(HRPU) - 0.8(LTK) + 0.24(SDC) - 2(SPT) + 0.03(TMR) \quad (3)$$

3.2 LOE 2: Understand the Trade Space Between Mobility and Lethality

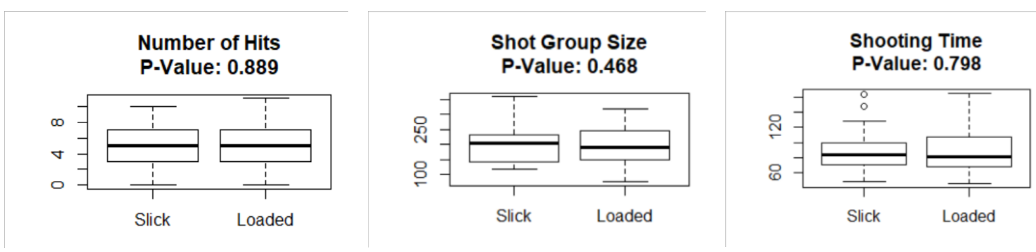

Figure 2. Box Plots of Lethality Response Variables with Displayed P-Values

In order to analyze the tradeoff between Soldier load and lethality, we first examined the effect of load on the number of targets hit, the participant's group size, and the time taken to fire all 20 rounds. We conducted a series of paired t-tests to see whether there was a statistical difference in the means using a 90% confidence interval. This means that we would need the p-value of the test to be less than the α value of 0.1 in order to conclude a difference in mean. However, Figure 2 shows there was a lot of overlap in the data, which resulted in high p-values; there was not enough statistical evidence to show there was a difference in any of the above response variables related to lethality. This result was the biggest surprise for our research as we hypothesized that when wearing the load, participants would be more tired and more uncomfortable shooting. However, some participants stated they were just as tired when running through the slick iteration because they pushed themselves to run faster.

Next, we looked to quantify the tradeoff between Soldier load and mobility by looking at the time to complete the first four obstacles, the time to complete the entire mobility course, and the number of obstacles failed. The overall distribution in times to complete first four obstacles are shown in Figure 3, with the median displayed as a dashed line. Using paired t-tests with a 90% confidence interval, we saw there was a statistical difference in mobility. On average, the participants took 34 seconds longer on the first four obstacles and 73 seconds longer on the entire MC while loaded, a 100% and 60% increase in time, respectively. Female times were affected more by the additional load than male times. Females, on average, took 67% longer to complete the MC when loaded, while males took 58% longer on average. Although we expected the decrease in speed, it is surprising to see that participants took twice as long to navigate the first four obstacles. This dramatic increase in time means they could be exposed to direct enemy fire for twice as long as they move to cover. The three shortest volunteers, all under 5’3”, failed to complete at least one obstacle; two volunteers failed the high wall and low wall while loaded and one volunteer failed the high wall while slick.

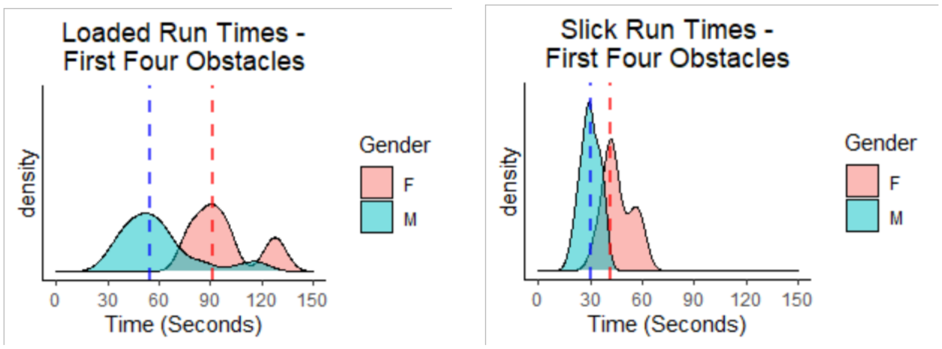

Figure 3. Distribution of Time to Complete First Four Obstacles

Finally, we conducted an analysis to see if we could predict how the participants would perform in the study based on their responses to our survey. We created a series of linear regression models to test for statistically significant impacts on performance. Models 1 and 3 looked to predict time to complete the mobility course using their IOCT time and gender. Next, models 2 and 4 predicted the time to finish based on the participant’s APFT scores and gender. Then, we tried to predict shooting performance (models 5 and 6) based on their last qualification score, their frequency of training over the previous six months, and the time since they had last qualified. While we found limited success in predicting times to finish the mobility course, there were no good predictors for a participant’s shooting performance. Table 2 has a summary of each of the models and which explanatory variables were statistically significant with an alpha value of 0.1.

Table 2. Linear Models for Predicting Mobility Course Time

Model	**Dependent Variable**	**Tested Explanatory Variables**	**Statistically Significant Variables**	**Adj. R^2**	**AIC**
1	Slick MC Time	IOCT Time, Gender	Gender	0.466	350
2	Slick MC Time	APFT Scores, Gender	Push-ups, Gender	0.495	349
3	Loaded MC Time	IOCT Time, Gender	IOCT Time, Gender	0.580	363
4	Loaded MC Time	APFT Scores, Gender	Two-Mile Run, Sit-ups, Gender	0.556	363
5	Target Hits	Qual. Score, Frequency of Training, Time Since Last Shot	None	n/a	n/a
6	Shot Group	Qual. Score, Frequency of Training, Time Since Last Shot	None	n/a	n/a

3.3 LOE 3: Understand the Trade Space Between Mobility and Survivability

We concluded our research by analyzing how changing mobility speed and protection affects survivability. Figure 4 provides an overview of the IWARS modeling results. Each colored shape in the figure corresponds to a run in the model. Females are represented in red and males are shown in blue. Triangles represent an armored (loaded) configuration, and circles represent slick configurations. Above each of the eight scenarios, the average survivability from the 50 runs is displayed. From the urban terrain model on the left side of Figure 4, we see that adding armor makes females more survivable on average but makes males less survivable. Perhaps the speed for slick females (1.9 ft/sec) was still too slow to avoid getting hit, but the slick males (2.9 ft/sec) were fast enough to push through the ambush. This shows that there is some threshold to where increasing mobility speed, even at the expense of body armor, can make soldiers more survivable in certain situations. Next, on the right side of Figure 4, the results from the open field terrain setting are displayed. In this model, we see that taking off armor in favor of moving faster causes both males and females to be less survivable. This indicates that when there is no cover or concealment, armor is essential – even if a Soldier is super mobile.

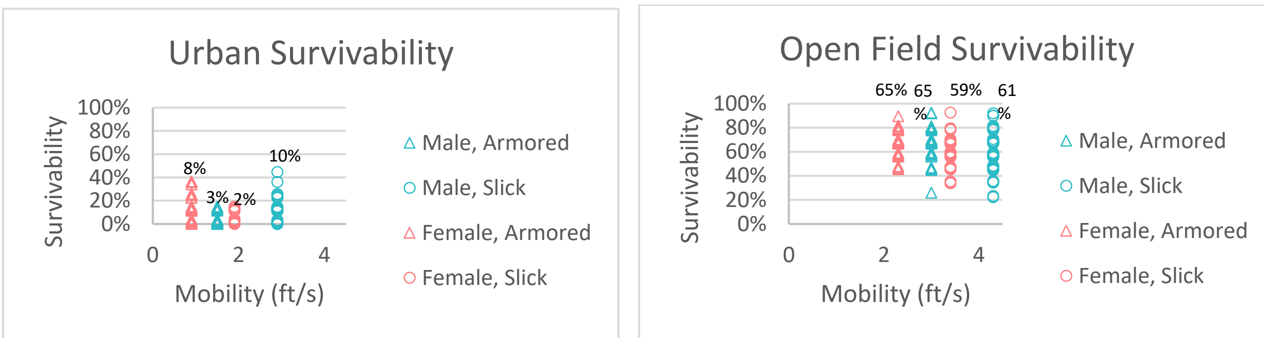

Figure 4. Survivability from IWARS Modeling (with Averages Displayed Above Each Scenario)

4. Conclusions and Future Work

Our research helped to further explore how Soldier load affects the trade space between mobility, lethality and survivability. In LOE 1, all three linear models we created have strong predictive power in a Soldier's mobility. LOE 2 showed that there is a clear decrease in the mobility of a Soldier as the weight they carry increases. LOE 3 showed that an increase in mobility due to less armor can make Soldiers less survivable in an open field terrain setting, but that may not be the case in an urban environment for highly mobile Soldiers. Also, our study found no evidence that additional load decreases a Soldier's lethality.

Future work in the area of Soldier mobility, lethality, and survivability should aim to tailor a Soldier's carrying load to maximize speed, agility, accurate firepower, and protection. Consider designing a study that incorporates more movement while shooting. Additionally, future study designs should require participants to use their own zeros or calibrations for aiming their rifles; this will make the number of targets hit a much better indicator of shooting ability. It would also be interesting to explore how the same load would affect Soldiers of varying sizes because the load a Soldier must carry does not usually vary based on how much that Soldier weighs. Finally, further modeling is warranted to see how mobility affects Soldier survivability in other mission sets and environments.

5. References

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