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Quantifying the Effects of Weapon Weight on Lethality through Holistic Modeling

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Abstract: Though it is widely known that weapon weight affects shooter stability, the quantitative effects on lethality and survivability are not well known. This issue stems from weapon lethality primarily being captured by equipment properties. A more holistic analysis can be performed by treating the soldier as a system by incorporating human factors with equipment performance specifications. This analysis requires the building of human factor models to appropriately capture lethality. The model development effort started with the collecting of data from experiments where the shot group accuracy was measured for weighted rifles. The resulting data was used to generate a mathematical model. This model, along with other human factor models, was integrated into the Weapon Lethality Service (WLS), a cloud-based simulation. The WLS was then set up to represent possible combat situations; the results were used to quantify the change in soldier lethality and survivability from changing the weapon weight.

Keywords: Soldier-Equipment-Task (SET), Weapon Lethality Service (WLS), Soldier, Equipment, Task, Lethality, Human Factor, Accuracy, Weight, Weapon, Model, Simulation

1. Introduction

New equipment for the United States military is often designed and tested to meet technical specifications that may not align with the actual operational usage of the equipment. Though these technical specifications can be traced back to capability gaps, these gaps address specific needs and do not holistically account for the soldier's use of the equipment in their actual operating environment. In particular, rifle design requirements focus on specifications such as range and rate of fire measured under ideal conditions; however, the actual effectiveness of the rifle in a combat situation would be based on the interaction between a soldier, the rifle, and the mission they are performing. The Natick Soldier Research, Development, and Engineering Center (NSRDEC) identified these problems and created the Soldier-Equipment-Task (SET) Framework to allow for a more holistic analysis of the operational effectiveness of new equipment. The SET Framework can be combined with modeling and simulation (M&S) to predict the impact of new equipment to key operational design parameters, such as lethality and survivability. This improved M&S capability will give the Army Acquisition community, researchers, and even commanders on the ground a better idea of soldier capabilities and likelihood of mission success.

2. Background Information

Weapons design has evolved throughout history to increase the effective range and rate of fire to make a soldier more lethal (Mittal, 2016). The M16 assault rifle was introduced into the US Army in 1964, with its current variant, the M4 assault rifle being introduced in 1994. Over the past few decades, the US Army has fielded numerous rifle attachments to provide soldiers with new capabilities. Figure 1 shows that these new attachments have resulted in an increase in weapon weight, with that weight added primarily to the barrel of the weapon. During Operation Desert Storm, few attachments were added to the weapon; however, the Global War on Terror resulted in a significant increase in the weight added to the weapon. Currently, the average rifleman is carrying an M150 Advanced Combat Optic, a weapon-mounted light, and a Storm Laser Range Finder on their M4, resulting in an increase of 2.3 lb. The grenadier in a rifle squad is carrying the M320 Grenade Launcher Module and the associated sight, which adds 3.9 lb (PEO Soldier, 2015). This trend is expected to increase with the addition of the next generation weapon sights (US Army MCOE, 2013).

Though these additions provide new capabilities to the soldier, the additional weight results in increased arm fatigue and less weapon stability, resulting in the soldier being less accurate with their weapon (Kemnitz, 1997). Though these new capabilities may have utility, the soldier's ability to complete a critical function—to shoot—is degraded. This issue resulted in the limited usage of the M26 shotgun as an attachment to the M4 (Poole, 2009). Though this issue is well known, the actual effects have not been quantified.

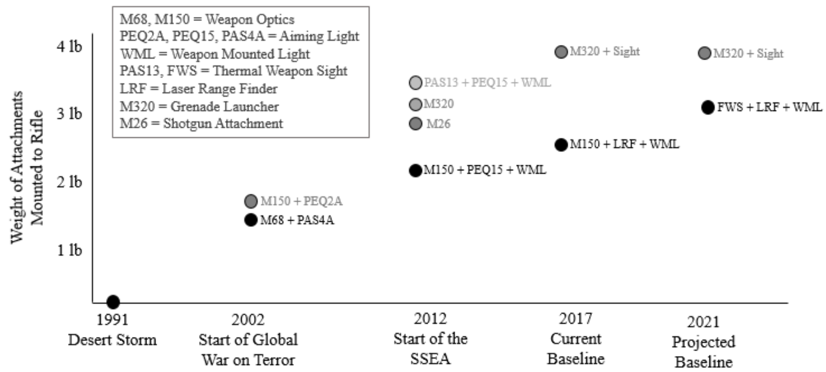

Figure 1. The weight increase associated with standard M16/M4 configurations over time.

2.1 SET Framework Overview

The Soldier-Equipment-Task (SET) Framework is an architectural framework designed to create a "system level trade-off analysis," allowing for the design of materiel solutions for soldiers in combat (Handley, 2017). The SET Framework treats the soldier as a system, where the overall system performance is based on the interaction between the soldier, their equipment, and their mission. This framework "balances human and technical capabilities with mission task" to make the soldier more capable (Handley, 2017). Figure 2 displays an example of analysis using the SET Framework. In this example, a new rifle variant could provide the soldier the ability to engage an enemy at a further distance by increasing the barrel length. However, through analysis using the SET Framework, it would be identified that the soldier is no longer able to accurately engage targets at that distance due to the increased barrel weight; additionally, the soldier's ability to engage close targets diminishes.

The SET Framework can work in unison with a Discrete Event Specification Distributed Modeling Framework (DEVS-DMF), to create a streamlined model of the effectiveness of soldiers in a combat mission. The DEVS-DMF framework is an M&S framework that integrates multiple stateless models into a discrete event simulation that can be implemented in a cloud environment (MacCalman, 2016). This M&S framework is ideal for providing M&S capabilities for the SET Framework because it allows for the compilation of a library of models produced by the different Army organizations that handle the different components of the SET Framework.

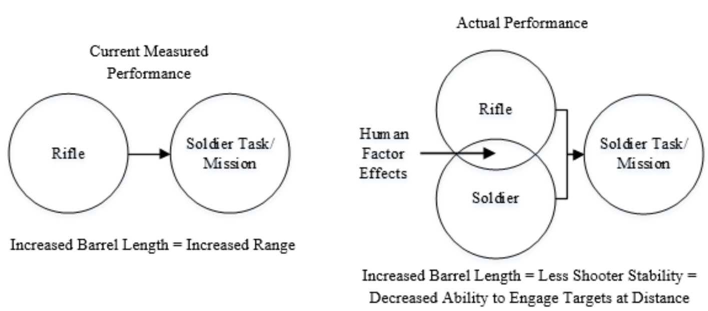

Figure 2. Measuring performance using traditional testing techniques (left) and the SET Framework (right).

2.2 Weapon Lethality Service

The Weapon Lethality Service (WLS) is a combat simulation coded in Scala and implemented in a cloud environment. The system produces data on incapacitation rates based on weapon and environmental parameters. In particular, the WLS takes weapon data, range to target, and environmental conditions to determine whether a soldier will incapacitate their target.

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The WLS is built on a DEVS-DMF platform, which readily allows for the integration of multiple models (MacCalman, 2016). As shown in Figure 3, this simulation utilizes the following three stateless models to determine the incapacitation of a target: Search and Target Acquisition, Delivery Accuracy, and Casualty Assessment. The Search and Target Acquisition model determines whether the soldier is able to detect and identify their target. Upon identifying their target, the soldier will shoot at the target, and the Munition Delivery Accuracy model determines where the bullet strikes relative to the target. The Casualty Assessment model then determines whether that round will incapacitate the target.

Since the system is designed in a DEVS-DMF, more models can easily be added to increase the capabilities of the model. Increasing the number of subcomponent models makes the overall service more powerful as it accounts for more factors of soldier performance. In particular, the addition of human factor models into the WLS would allow for a more holistic analysis in line with the SET framework.

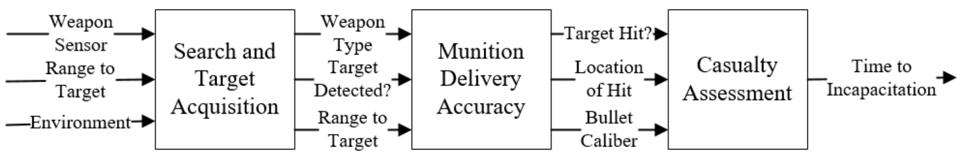

Figure 3. Models that comprise the Weapon Lethality Service.

3. Model Development

3.1 Data Collection and Analysis

Though several studies provide anecdotal evidence that increased weapon weight degraded the shot group accuracy, a quantitative model did not exist. Therefore, experimental test data was collected on the Engagement Skills Trainer 2000 (EST2000) with 35 test subjects to identify the degradation in shot group accuracy associated with the addition of 3 lb added to the barrel of a weapon. The EST2000 is an indoor, multi-purpose, multi-lane, small arms training simulator. It provides detailed feedback to either the individual or unit training. Test subjects spent ten minutes carrying a simulated weighted weapon to familiarize their muscles with the weapon weight. They then fired two, ten-round magazines from a standing position at a simulated target at 175 meters. The size of the shot group was recorded. The following day, the experiments were repeated with a standard non-weighted weapon.

The data collected quantified the expected trend - shot group accuracy decreased as weapon weight increased. A statistical analysis was performed on the experimental data to determine that an increase in weapon weight by 3 lb increased the size of the shot group by 17.6 percent.

3.2 Model Design Process

The experimental data was used to build a stateless model for integration into the WLS. This new model followed a traditional systems design process consisting of three sequential phases: preliminary, conceptual, and detailed designs. As shown in Figure 4, preliminary design consisted of constructing IDEF0 diagrams from data gathered from research, which visually organized the inputs and outputs of the model. The conceptual design phase involved translating the IDEF0 for weapon lethality into a basic mathematical model built in Microsoft Excel. Finally, the detailed design integrated the mathematical models into the WLS using Scala code.

The design phases align with verification and validation steps. Verification of the model was performed by executing 120,000 runs of the model to ensure that the model was properly integrated into the WLS. Validation was performed by comparing the final results of the analysis to additional tests run on the EST2000.

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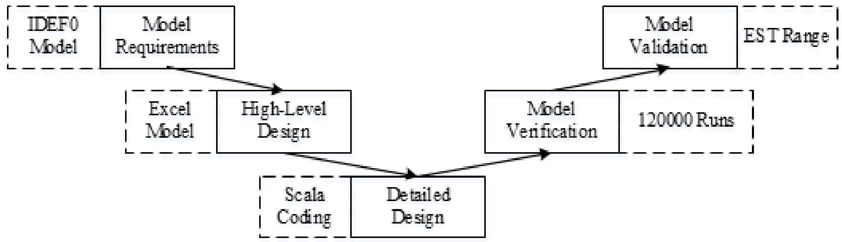

Figure 4. This modified Systems Engineering "V" shows the process of in-depth design (left side) before shifting to testing and integration (right side).

4. Integration into WLS

4.1 Addition of Supplemental of Models

The mathematical model for the effects of weapon weight on shot group accuracy was converted into Scala coding such that it could be integrated into the WLS. A second model for changes in shot group accuracy based on the shooter heart rate was also integrated into the WLS, based on the equations given in Markey (2016). These two models were built into stateless functions that were instantiated in the Munition Delivery Accuracy model, as shown in Figure 5.

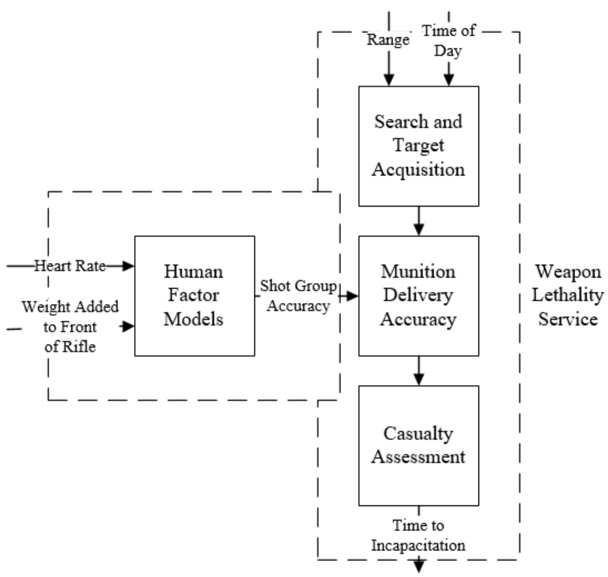

Figure 5. The integration of Human Factor Models based on weapon weight and heart rate into the WLS.

Also shown in Figure 5, the Search and Target Acquisition and Casualty Assessment models did not require alteration due to their separate, yet dependent, nature. Once the models were integrated into the WLS, the service underwent verification by ensuring that the code functioned properly with no errors. This process was set by running the model against the EST2000 test conditions and ensuring that the simulation results matched the experimental results. The code could then be used with new inputs to gain the appropriate output data.

4.2 Capturing Lethality and Survivability

The modified WLS can quantitatively capture the impact of weapon weight on a soldier's overall lethality and survivability. The WLS was run in the configuration shown in Figure 6, where two simulations were run in parallel. The first

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simulation involves an M4 firer engaging an AK47 firer at a given range; the second simulation has an AK47 firer engage the M4 firer at that same range. Each simulation outputs the amount of time required for incapacitation. These times are then compared to determine who won the engagement.

These simulations were run at six different test configurations for the weighted and unweighted M4. These test configurations represent different environmental conditions in which soldiers tend to operate. The time of day was altered to represent both day and night operations. The environment was varied between urban, rural, and mountain terrain. These environmental factors effected the ranges and heart rate of the soldier. The urban environment had soldiers engaging at 50 m with a heart rate of 170 bpm; the rural environment at 200 m and 120 bpm; the mountain environment at 500 m and 70 bpm.

The simulation was run 10,000 times at each test condition, with a sensitivity analysis being performed to ensure that 10,000 was an adequate number of runs. A survivability metric was defined as being the percentage of times that the M4 firer was not killed by the AK47 firer. A lethality metric was defined as being the percentage of times that the M4 firer killed the AK47 firer. These two metrics can readily be used in comparative analysis to identify the likelihood of incapacitation given common operational conditions and added weight to the weapon system.

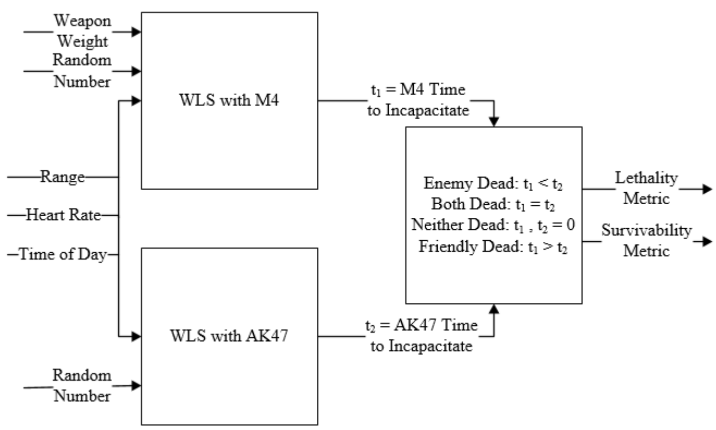

Figure 6. Simulation framework for capturing lethality and survivability through the WLS.

5. Results

Table 1 provides the breakdown of incapacitation rates by test condition. As expected, the M4 firer's incapacitation rate decreased when weight was added to the rifle. In addition to decreased lethality, the effect of adding weight also increased the incapacitation rate of the AK47 firer, thus resulting in decreased survivability. Note that the simulation did not produce a "winner" if neither the M4 nor the AK47 were able to incapacitate their target. This may be due to inaccuracy of the shots fired but can primarily be attributed to an inability to detect the target, which is the first mechanism of the simulation and is required for the subsequent mechanisms to occur. As shown in Table 1, at the 200 m and 500 m ranges, the shooters did not detect each other at night.

The simulation quantified lethality by identifying the percentage of times that the M4 firer killed the AK47 firer; survivability was quantified by the percentage of times the AK47 firer killed the M4 firer. The results show that adding 3 lb to the weapon correlates to a decrease in lethality of 17.3 percent across all these operating conditions. Similarly, the addition of 3 lb to the weapon correlates to a decrease in survivability by 11.6 percent. These effects are extenuated at longer ranges. These quantified effects can then be used by stakeholders to determine whether new capabilities that are associated with new weapon mounted equipment offset these decreases in lethality and survivability.

Table 1. The six test conditions with their respective parameters and outputs for the effect of weight on both the M4 (lethality metric) and the M4 vs. AK47 (survivability metric).

Setting				Lethality Metric		Survivability Metric	
Treatment Combination	Range (m)	Heart Rate (bpm)	Time of Day	% of M4 Kills - Unweighted M4 Scenario	% of M4 Kills - Weighted M4 Scenario	% of AK47 Kills - Unweighted M4 Scenario	% of AK47 Kills - Weighted M4 Scenario
1	50	170	Day	47.6%	41.0%	52.3%	58.7%
2	50	170	Night	2.6%	2.6%	2.8%	2.9%
3	200	120	Day	42.1%	34.7%	48.6%	53.0%
4	200	120	Night	0.0%	0.0%	0.0%	0.0%
5	500	70	Day	14.0%	10.6%	17.7%	18.4%
6	500	70	Night	0.0%	0.0%	0.0%	0.0%

Note: For the 200 m range and 500 m range, targets did not detect each other or engage at night.

6. Conclusions

Studies have shown that an increase in weapon weight due to the addition of new capabilities can result in soldiers being less able to engage targets, potentially decreasing their overall lethality and survivability. Experiments were conducted to build a mathematical model for integration into the WLS to quantify these changes in survivability and lethality. The analysis found that a 3 lb addition to the weapon resulted in a reduction of lethality by 17.3 percent and a reduction in survivability of 11.6 percent. The manipulation of the WLS provides a significant case study to show that the application of the SET Framework can have a paramount role in accurately modeling the soldier's capabilities for the US military. Additionally, it addresses a number of critical questions that stakeholders have, such as how to accurately quantify lethality and survivability in equipment design. The results from this case study follow expected lethality trends generally understood by military commanders but serves to quantify their effect, providing a more realistic understanding of its significance.

Although this case study specifically focuses on the effect of additional weapon weight on lethality and survivability, the underlying process can be applied to the modeling of other military systems to ensure holistic human factor designs. These models can then support system design, specifically technical requirements and military trade-space analysis. This research suggests that the application of the SET Framework to modeling can lead to both a more complete representation of the nature of the battlefield and an increased understanding of soldier performance.

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