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# Quantifying Time to Aim for Soldier Lethality

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**Author Note:** Dewayne Coleman, Stryker Gay, Edward Hummel, Trae McDaniel, and Cooper Schodrof are Cadets majoring in Engineering Management at the United States Military Academy. This work is the author's academic capstone project in the Department of Systems Engineering (DSE). Colonel Brandon Thompson, Ph.D., the program director of Engineering Management in the Department of Systems Engineering, served as the capstone project advisor. The views expressed herein are those of the authors and do not reflect the position of the United States Military Academy, the Department of the Army, or the Department of War.

**Abstract:** This research sought to develop and validate a standardized method for quantifying a soldier's Time to Aim (TTA) a rifle, defined as the interval between target acquisition and trigger pull. Using a systems engineering design methodology, this team conducted value modeling to define TTA, evaluate sensor-based measurement devices, and analyze data-collection technologies. The team designed an experiment using a rifle marksmanship simulation to test two measurement sensors and determine the effects of two body armor protection plates (Army ESAPI and a future concept prototype) on timing, accuracy, and mobility. While little difference was found between the value scoring of the two measurement sensors (Actigraph and MantisX), the human factors experiment demonstrated advantages of the MantisX sensor regarding data analysis. In addition, the experiment found little difference in perceived TTA between the two protection plates, but participants reported higher perceived accuracy, comfort, and mobility while using the future concept prototype plate.

*Keywords:* Time to Aim, Engagement Skills Trainer, Human Factors Experiment

## 1. Background

Modern warfare demands rapid advancement and adaptable lethality at the individual soldier level. As the Army continues to modernize its weapon systems and equipment for soldiers, the ability to quantitatively evaluate how these systems affect a soldier's performance has become increasingly critical. Soldier lethality is doctrinally defined as the capability and capacity to neutralize or destroy an enemy target (Hinck et al., 2025). Lethality is thus a critical component of combat effectiveness. However, there is currently a critical gap early in the development process in the ability to measure the effects of these equipment advancements on lethality and a soldier's Time-to-Aim (TTA) in the field.

TTA is generally defined as the elapsed interval between initial target presentation and the moment the weapon reaches a stable firing condition prior to trigger pull. Contemporary research treats aiming as a multi-stage motor-perceptual process involving acquisition, stabilization, and engagement, which can be quantified using metrics such as aim-trace variance, RMS error, or pre-shot movement velocity (Jones, King, & Gaydos, 2011). Sensor-based approaches can be used to quantify the metric by identifying when weapon micro-movements fall within a stability threshold, highlighting the important trade-off between engagement speed and shot accuracy. In addition, prior research using the Infantry Warrior Simulation (IWARS) provided a combat modeling framework that decomposed soldier actions into measurable behavioral components such as sensing, target acquisition, aiming, and engagement (Tollefson, Reynolds, & Chou, 2025). Within this framework, variations in TTA and movement behavior were linked to performance outcomes including engagement success, survivability, and overall mission effectiveness. The challenge is to replicate the effects of TTA within the simulated environment to human performance in operational environments (Goldberg et al., 2014; Hancock, Ross, & Szalma, 2025). While existing U.S. Army lethality assessments emphasize time to fire, accuracy, and engagement outcomes, no doctrinally aligned or experimentally validated framework currently exists to measure TTA in either live-fire or simulation environments (Goldberg et al., 2014; Brown & Mitchell, 2017; Vickers & Lewinski, 2012). This gap limits the U.S. Army's ability to determine how equipment, specifically body armor and weapons, influences TTA and overall lethality.

The U.S. Army Transformation Decision Analysis Center (TDAC) within the Futures and Concepts Command of Transformation and Training Command (T2COM) identified the lack of a TTA assessment method as a critical capability gap. Current small-arms test protocols do not include a validated, repeatable method to quantify TTA, restricting TDAC's ability to evaluate how equipment design and next-generation kits affect soldier engagement performance in tactical situations. The research team worked with TDAC to address the TTA problem using a systems engineering approach and conducted a human factors experiment using a rifle marksmanship simulator to evaluate two measurement devices' ability to assess TTA for a representative example of two different body armor plates.

The desired end state was a scientifically defensible protocol that TDAC could employ in future testing situations, strengthening the U.S. Army's ability to assess small arms systems, next-generation equipment integration, and training effectiveness. This research specifically sought to identify a measurement sensor that could be used to accurately and consistently measure TTA to evaluate emerging soldier equipment systems.

## 2. Introduction

This study evaluates a method for quantifying TTA using a rifle marksmanship simulation system, the Engagement Skills Trainer (EST 2000), while assessing the effects of different body armor protection plates on aiming performance. To establish a reliable method for measuring TTA, value-based modeling using the Systems Decision Process (SDP) was used to identify system requirements, select candidate sensor measurement devices, and identify the most effective device to capture weapon stabilization and effective shot timing. The study also examines alternative measurement approaches to determine their effectiveness in capturing TTA and characterizing weapon stabilization behavior.

Following the identification and scoring of measurement sensor devices, a human factors experiment was conducted to evaluate two sensor alternatives' ability to accurately and reliably measure TTA. In addition, as a representative application of the sensors measurement of TTA, the team evaluated the effects of two body armor plates on the timing, accuracy, comfort, and mobility during the simulated rifle qualification.

The objective of this study was to develop and validate a repeatable method for measuring TTA, evaluate measurement approaches, and assess the impact of body armor configurations on aiming performance.

## 3. Methodology

### 3.1 Problem Definition

Prior to conducting experimental testing, the research team evaluated the operational relevance of TTA through simulation-based combat modeling. Agent-based modeling conducted using the IWARS framework was used to examine how variations in soldier aiming behavior influence lethality outcomes in tactical scenarios. Within this modeling environment, soldier actions such as target acquisition, stabilization, and engagement were decomposed into measurable performance components. Simulation results indicated that reductions in TTA were associated with improved engagement success and increased probability of neutralizing enemy targets. These findings demonstrated that aiming efficiency is a meaningful contributor to overall soldier lethality and provided justification for further experimental investigation. The IWARS modeling effort therefore established the operational significance of TTA and supported the transition from conceptual performance modeling to controlled experimental measurement.

### 3.2 Value-Based Modeling

Following confirmation of TTA importance through simulation modeling, the team conducted value-based modeling using the Systems Decision Making Process (SDP) to redefine the problem, determine system requirements necessary to measure TTA in a repeatable and operationally relevant manner, and evaluate potential TTA measurement devices. The experimental methodology was developed using the SDP to ensure that the measurement process was scalable, reliable, and capable of supporting TDAC analysis needs.

The research team conducted stakeholder analysis to develop a value hierarchy with the fundamental objective to quantify a TTA, Figure 1. The value hierarchy emphasized several key functional requirements, including conducting measurements, enabling test execution, and supporting data field collection. Objective functions and value measures were then derived to evaluate the ability of candidate solutions to satisfy the functional requirements. The research team then worked with stakeholders to develop value functions for each value measure. The value functions enabled the team to translate sensor-based measurement device capabilities into normalized value scores. Finally, pairwise comparisons of each value measure were performed by stakeholders and the research team to create weights for each value measure. Each value measure was rated against the others one-by-one to identify the most important measure between the pairs. The total wins were then counted for each value measure and weights then derived by calculating the percentage of wins for each value measure out of the total number of wins. Once the value-based model was developed, the team researched potential sensor-based measurement devices capable of measuring TTA and developed a method to evaluate the sensors' performance.

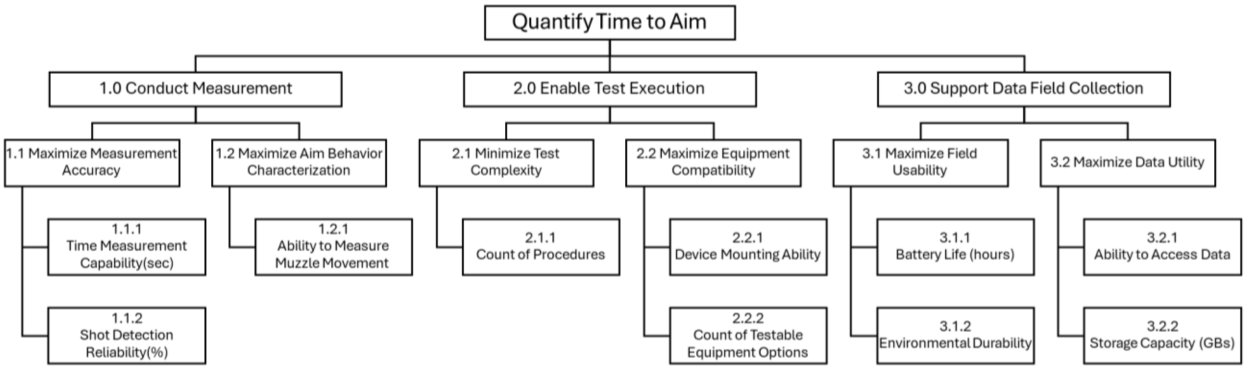


Figure 1: Time to Aim Value Hierarchy

Two sensor-based measurement technologies were identified as candidate solutions, the MantisX firearm training sensor and the Actigraph tri-axial accelerometer, Figure 2. Both devices could be mounted to the M4 rail system and could capture weapon movement data associated with aiming stabilization behavior.

a. b. c.

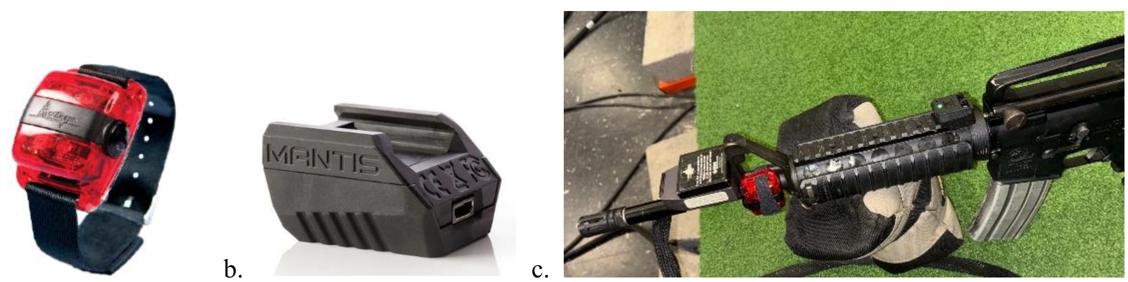


Figure 2: a. Actigraph, b. MantisX, c. EST M4 Rifle with Actigraph and MantisX attached

## 3.3 Weighted Scoring and Sensitivity Analysis

Upon selection of the two measurement devices, the research team scored each device using the value functions for each value measure. The normalized value scores were multiplied by the weights for each value measure and summed resulting in a total candidate score for both the Actigraph and MantisX. Table 1 displays the resulting weighted scoring model with both devices receiving a total score of 72.

As a result of the similar total candidate scores, the team conducted a sensitivity analysis to evaluate how changes in value measure weighting affected the ranking of the Actigraph and MantisX. The sensitivity analysis identified five value measures that were very sensitive to changes in weighting. The Actigraph device had a higher value score for ability to measure muzzle movement, time measurement capability, environmental durability, and storage capacity. As a result, increasing the weights on any of those four value measures resulting in a higher candidate score for the Actigraph and decreasing the weight resulting in the MantisX being the preferred device. The MantisX had a higher value score for shot detection reliability resulting in a higher candidate score for the MantisX if the weight was increased and the Actigraph if the weight was decreased. Figure 3 displays the sensitivity curves for each of the five sensitive valued measures when the weight is changed. Difference in candidate scores (Actigraph score – MantisX score) is shown on the y-axis with positive scores representing conditions where the Actigraph is preferred and negative scores where the MantisX is preferred. The x-axis displays the changes to the value measure weight.

Table 1: Weighed Scoring Model for Actigraph and MantisX

| | | | Value Scores | | Weighted Scores | |
|---|---|---|---|---|---|---|
| | | **Weights** | **Actigraph** | **MantisX** | **Actigraph** | **MantisX** |
| Maximize Usability | Device Mounting Ability | 0.08 | 50 | 90 | 3.8 | 6.8 |
| | Count of Operating Procedures | 0.03 | 45 | 65 | 1.1 | 1.6 |
| Maximize Accuracy | Ability to Measure Muzzle Movement | 0.17 | 70 | 50 | 12.2 | 8.7 |
| | Shot Detection Reliability | 0.14 | 40 | 100 | 5.7 | 14.2 |
| Maximize Fidelity | Time Measurement Capability | 0.14 | 90 | 70 | 13.0 | 10.1 |
| Maximize Operation | Battery Life | 0.06 | 100 | 90 | 5.8 | 5.2 |
| Maximize Data | Ability to Access Data | 0.10 | 50 | 50 | 4.9 | 4.9 |
| | Storage Capacity | 0.06 | 80 | 50 | 4.9 | 3.0 |
| Maximize Flexibility | Testable Equipment Option | 0.11 | 100 | 100 | 10.6 | 10.6 |
| Maximize Durability | Environmental Durability | 0.11 | 90 | 60 | 10.3 | 6.8 |
| | | | | | **72.3** | **72.2** |

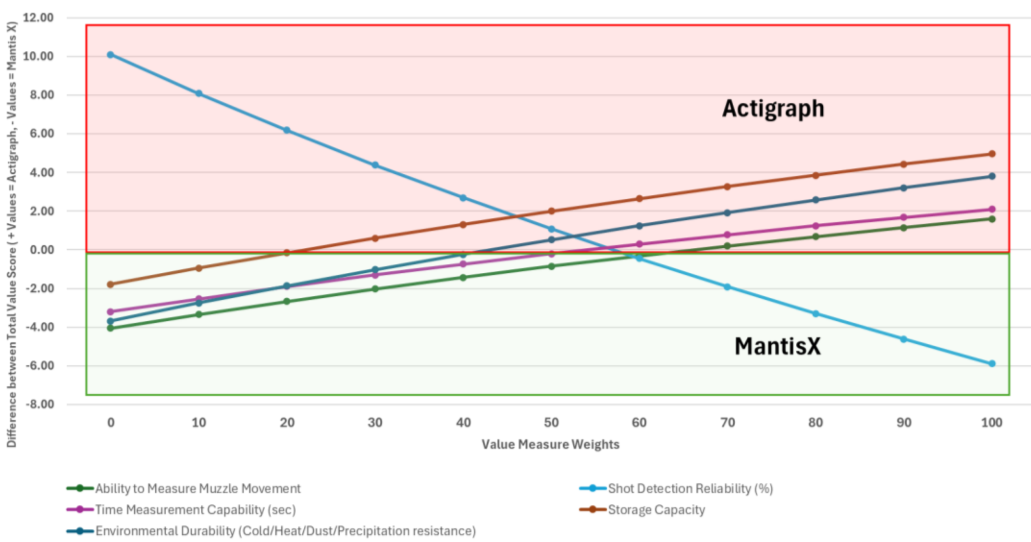


Figure 4: Sensitivity Analysis of Value Measure Weights (difference of device scores, Actigraph – MantisX)

### 3.4 Human Factors Experiment

As a result of the similar value scores, the team designed a human factors experiment to test both devices' ability to measure TTA. Two primary experimental factors were evaluated. The first factor consisted of the two sensor-based measurement devices, Actigraph and MantisX. Both devices were affixed to the simulation M4 rifle as shown in Figure 2c. The second factor was body armor configuration, consisting of a standard Army Enhanced Small Arms Protective Insert (ESAPI) plate and a future concept prototype plate. Two different body armor plates were included as a representative comparison of current and future generation kit that may be evaluated to assess impact to lethality through TTA. These configurations were selected to evaluate the TTA effects on a shooter's mobility, weapon handling dynamics, and stabilization behavior during engagement. All experimental trials were conducted using the EST 2000 located within the West Point Simulation Center. The EST 2000 is a simulation-based small-arms training system designed to replicate realistic engagement scenarios while providing detailed shot-level telemetry, including shot timing, hit-miss accuracy, and muzzle trace movement. The controlled simulation environment eliminated environmental variability such as lighting changes, terrain effects, and weather conditions, thereby supporting the objective of isolating equipment effects on TTA. The EST 2000 was selected as the test apparatus as it provided a known point of comparison to the outcomes from the MantisX and Actigraph because the weapon is instrumented and integrated with the simulated targets.

During each trial, participants completed standardized Army Table V qualification scenarios consisting of multiple target engagements. Continuous tri-axial acceleration data were collected at a sampling rate of 100 Hz using the Actigraph

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sensor, while shot timing and weapon movement metrics were recorded using the MantisX system. TTA was defined as the interval between target presentation and trigger pull. Additional response variables included participant perceived shot accuracy, timing, mobility, and comfort ratings for each armor condition. After the qualification under each type of body armor plate, participants were administered a survey asking how the body armor plate affected their level of comfort, accuracy, time to aim, and mobility using a five-point Likert scale.

Randomization and counterbalancing procedures were implemented to reduce learning and fatigue effects associated with trial sequencing. Replication was achieved through repeated engagement events within each qualification course, improving measurement precision and supporting reliable comparison between measurement systems. Collectively, the controlled experimental design enabled evaluation of both equipment effects on aiming performance and the feasibility of sensor-based methods for quantifying TTA.

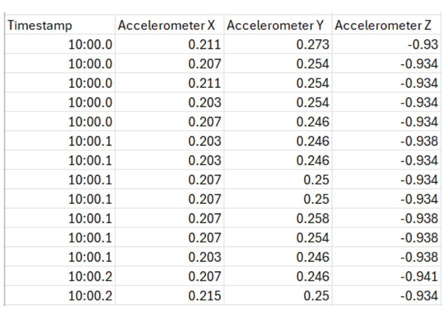
## 4. Results and Recommendations

### 4.1. Measurement Sensor Comparison: Actigraph versus MantisX

When the researchers initially started testing TTA, the first challenge was to identify a method for synchronizing the time intervals of each device with the timing of the EST target presentation. For the Actigraph, the team recorded the world clock time when the qualification started and aligned it with the times given within the Actigraph Microsoft Excel output, see Figure 6. For the MantisX, the team was able to record the targets when they appeared in the EST simulation and when the targets were engaged by recording the MantisX application on a cell phone situated in front of the EST control monitor displaying the target presentations, see Figure 7. The research team initially assessed that the Actigraph would be the most viable option due to the abundance of data the device was able to collect.

The Actigraph's volume of data presented challenges with identifying the gunshot signature and synchronizing the accelerometer data with the EST target presentations. The team attempted to isolate the action of taking aim and firing a single shot within the Actigraph output data manually and with the assistance of generative artificial intelligence platforms such as Microsoft's CoPilot and OpenAI's ChatGPT. The team was able to identify shots using generative AI but experienced significant challenges synchronizing the Actigraph data timing with the EST target presentation to measure a TTA preventing the ability to accurately and consistently measure the TTA.

The MantisX output was measured from the software application downloaded on a cellular phone. The MantisX software application displays a trace of the aiming location of the riffle muzzle and indicates the gunshot with a burst on the screen before resuming muzzle trace. This allowed the researchers to record a video capturing the exact moment at which the barrel stabilized (the aiming component) and the moment the subject pulls the trigger. The team was able to record a video that captured the target presentation as well as a live muzzle trace feed from MantisX. Again, using generative AI, the team was able to evaluate the video frame-by-frame to detect the target presentation on the EST screen and trigger pull on the MantisX application. Table 2 displays the descriptive statistics for the six participants' TTA on a standard Army Table V qualification.



| Timestamp | Accelerometer X | Accelerometer Y | Accelerometer Z |
|---|---|---|---|
| 10:00.0 | 0.211 | 0.273 | -0.93 |
| 10:00.0 | 0.207 | 0.254 | -0.934 |
| 10:00.0 | 0.211 | 0.254 | -0.934 |
| 10:00.0 | 0.203 | 0.254 | -0.934 |
| 10:00.0 | 0.207 | 0.246 | -0.934 |
| 10:00.1 | 0.203 | 0.246 | -0.938 |
| 10:00.1 | 0.203 | 0.246 | -0.934 |
| 10:00.1 | 0.207 | 0.25 | -0.934 |
| 10:00.1 | 0.207 | 0.25 | -0.934 |
| 10:00.1 | 0.207 | 0.258 | -0.938 |
| 10:00.1 | 0.207 | 0.254 | -0.938 |
| 10:00.1 | 0.203 | 0.246 | -0.938 |
| 10:00.2 | 0.207 | 0.246 | -0.941 |
| 10:00.2 | 0.215 | 0.25 | -0.934 |

Figure 6: Actigraph Excel Data

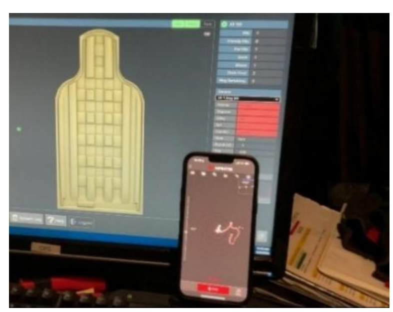


Figure 7: EST target and MantisX Video Recording

As a result of the team's data collection and analysis results, the research team recommends the development of a dedicated measurement device or a modified version of the MantisX system. The system would ideally be implemented within a controlled simulation, such as the EST or any environment where the researchers can control for the timing of target presentation synchronized with MantisX application.

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Table 2: MantisX Time to Aim data summary statistics (in seconds)

| Sample Size (n) | Mean (sec) | Standard Deviation (sec) | Minimum (sec) | 25th Percentile (sec) | Median (sec) | 75th Percentile (sec) | Maximum (sec) |
|---|---|---|---|---|---|---|---|
| 6 | 3.70 | 1.19 | 1.88 | 3.02 | 4.06 | 4.28 | 5.15 |

### 4.2. Body Armor Differences

A secondary purpose for conducting this experiment was to gain a better understanding of the effects of different body armor plates on a shooter's accuracy, timing, mobility, and perceived comfort. After conducting the simulated Army Table V qualification, participants reported the future concept prototype plate was more comfortable, allowed for higher accuracy, and provided more mobility than the standard Army ESAPI. However, the participants rated their perceived accuracy the same under both armor plates. Table 3 displays the subjective ratings, Mean (Standard Deviation), for assessment criteria.

Table 3: Participant Perceived Impact of Body Armor Plate Type, Mean (Standard Deviation)

| | Comfort | Accuracy | Timing | Mobility |
|---|---|---|---|---|
| Standard Army ESAPI | 3.5 (1.0) | 3.5 (0.6) | 3.0 (0.8) | 2.75 (1.0) |
| Future Concept Prototype | 3.75 (0.5) | 3.75 (0.5) | 3.0 (1.2) | 3.5 (1.3) |

## 5. Conclusion

By isolating and measuring the fine-aiming phase of target engagement, this research contributes to a more complete understanding of soldier lethality, bridging the gap between equipment performance and human performance in combat-relevant situations. Ultimately, quantifying TTA will provide TDAC and the Army with a data-driven system to inform acquisition decisions and enhance operational effectiveness. Based on the findings of this project, the research team recommends field testing the MantisX device and software application to provide the ability to measure TTA due to easier post-processing of data as compared to the Actigraph. In addition, testing and documenting the effects of the future concept prototype SAPI plate will provide valuable data to T2COM.

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