Using COTS Software to Capture Deliberate and Reactive Weapons Firing Behavior: Lessons Learned in Knowledge Acquisition

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ABSTRACT: *This paper reports on a methodology developed to collect data for the development of an individual combatants' (IC) weapons firing algorithm (WFA). The objective was to collect data that would reveal which factors were the most influential and how the priorities of these factors could change over a variety of scenarios. After determining that existing manuals and documentation did not adequately support definition of such an algorithm, a knowledge acquisition methodology based on scenario drills capturing empirical data and interviews capturing introspective data was developed and implemented. Analysis of SME responses suggests that some of the IC-WFA is subject to individual differences and preferences, but other parts are based on common principles shared by many SMEs. Thus, in areas where individual differences are prevalent, empirically generated data was used to characterize the decision space, and in areas where individual differences are less prevalent, general heuristics were used to characterize the decision space. The work conducted lays the foundation for a plan to develop a more robust and realistic model based on representative empirical distributions that will support the types of analyses performed with the Integrated Unit Simulation System (IUSS).*

1. Introduction

This paper reports on the knowledge acquisition (KA) methodology used to develop a weapons firing algorithm (WFA) for individual combatant (IC) entities represented in the Integrated Unit Simulation System (IUSS). IUSS is a force-on-force model used by analysts to make acquisition and materiel design decisions affecting individual soldiers and small units in high-resolution combat and operations other than war. It provides psychological and physiological representation of the individual (e.g., heat, stress, fatigue, load sustainment, hydration, etc.), influenced by environmental factors (e.g., dynamic weather, rough terrain, variable lighting conditions, etc.) and battlefield threats (e.g., flame, laser, ballistics, etc.). Although high-level scripted behaviors have been developed for individual combatant (IC) object models in IUSS, improved techniques that provide for more accurate, robust IC weapon firing models are required to adequately support the needs of the analysts. In tune with current trends in human behavior representation [1] and consistent with the needs of simulations used in the analysis community, the emphasis of this research is placed on the use of human performance data to better understand and model the capabilities and behaviors of the human dynamic as it relates to weapon firing.

Our general approach was to develop an algorithm heuristically, through the use of data/knowledge collected through interviews with subject matter experts (SMEs). This decision was a result of two factors. First, through review of pertinent documentation, it was determined that existing U.S. Army Field Manuals (FMs) for infantrymen (individual, dismounted soldiers) do not describe the weapons firing algorithm in detail sufficient to develop an adequate model for IUSS. While these FMs do provide a good deal of introduction and high-level overview of the problems, they do not closely examine how complex factors affecting the IC weapons firing algorithm can interact. For example, Army manuals [2] indicate that target priority is assigned to the “most dangerous or threatening target” or recommends that an IC “perform terrain analysis” (e.g., determine dead space or establishing a fire position). Both of these procedures (target prioritization and terrain analysis), as demonstrated in future sections of this paper, are critical to the formation of an IC-WFA; however, both are subject to individual differences. Thus, FMs cannot be used in isolation to develop an algorithm adequate for this application.

The second reason we decided to develop this algorithm through heuristics is because we determined that comprehensive and formal experimental methods would not be feasible for a problem of this scope. For example, merely assuming the following factors and levels for determining the threat value of a target:

Smoke: <smoke, no smoke>
Cover and Concealment: <cover, concealment, none>
Posture: <standing, kneeling, prone>
Distance: <near, medium, far>
Aim Point: <at You, at Friendly, none>
Speed: <running, stationary>
Direction: <toward you, toward friendly, to flank>
Placing Fire: <well, not well>
Weapon: <MG, RPG, rifle>
Role: <officer, sniper, soldier>

would yield

$$2*3*3*3*3*2*3*2*3*3 = 17496 \quad (1)$$

combinations for a single target. As a result, comprehensive pair-wise comparisons would require:

$$(17496^2)/2 = 153{,}055{,}008 \text{ tests} \quad (2)$$

Thus, even for a very constrained set of factors and comparisons, the number of tests required to perform a full-factorial experiment is unwieldy. Further, this estimate is merely for high-level aggregate descriptions of these 10 factors. Realistically, there are other factors and many “shades of gray” in between the levels of the factors as expressed above which make these numbers even higher. Unfortunately, research has shown that introspective methods do not work well for highly complicated decision spaces [3]. Also, research has shown that the way SMEs believe they perform some task is not necessarily congruent with how they actually perform the task [4]. Lastly, other researchers have shown that modeling human behavior with human performance data results in high fidelity models [5]. Thus, we found ourselves caught between the proverbial rock and a hard place. We had a large decision space to cover. We wanted our data to be free from biases associated with introspective methods. But, we could not comprehensively cover the decision space with highly objective KA strategies.

The combination of these issues motivated our approach to develop the WFA through a blend of interview data and observational data acquired from SMEs. That is, in the larger but less complicated sections of decision space, we used simple heuristics derived from interviews, but in the other more complicated sections we relied on comparisons of empirically generated, observation data. We believe that the use of observational data is key to developing a model that would be representative of human behavior. And, we believe that a model that is representative of human behavior is key to supporting the needs of the analysis community.

2. Methodology

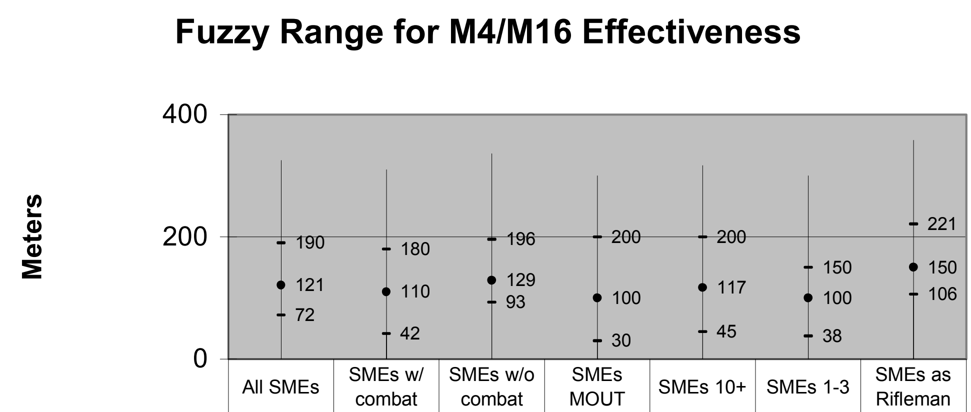
Generally, the approach we used was to query SMEs with help of a visual scenario presented in a slide format. This information was coupled with a questionnaire.

2.1 Subject Questionnaires

Subject questionnaires were distributed to develop demographics of infantrymen participating in this study. For the formal knowledge acquisition (KA) effort, a total 12 SMEs were used. Table 1 presents some of the data.

Demographic	Categories	Number of SMEs
RANK	CIV (ret)	3
	CPT	4
	LTC	1
	SFC	2
	MAJ	1
	MSG	1
AGE	26 – 30	2
	31 – 36	3
	37 – 42	4
	43+	3
Years since Battle Drill Training	2 or less	8
	2 to 5	2
	Over 6	2
# of actual Fire fights	None	7
	1 to 3	2
	4 to 9	0
	10 or more	3
Positions Covered: Platoon Leaders, Squad Leaders, Fire Team Leaders, Platoon Sergeants, Riflemen, Snipers, Machine Gunners, SAW Gunners, Grenadiers, Company Commanders, Company First Sergeants, and Anti-Tank Gunners.		

Table 1. SME Demographic Data



	All SMEs	SMEs w/ combat	SMEs w/o combat	SMEs MOUT	SMEs 10+	SMEs 1-3	SMEs as Rifleman
- Easy-Combat	72	42	93	30	45	38	106
● Medium-Combat	121	110	129	100	117	100	150
- Difficult-Combat	190	180	196	200	200	150	221
Easy - Range	115	95	129	75	92	100	138
Medium-Range	223	215	229	192	200	238	234
Difficult-Range	325	310	336	300	317	300	358

Group Responding to Query

Figure 1. Average of Group Values Assigned to Effective Range of Rifles (M4/M16)

While most of the information from questionnaires was demographic in nature, a few other important pieces of data were acquired through the questionnaire. This information included some of the following:

1) differences between Open Field and MOUT combat that could affect target selection or weapon preference,
2) perceived effective ranges of a variety of weapons
3) rankings of factors influencing threat assessment of target in Open Field, urban canyon, and closed-quartered building scenarios.

An example of the second type of data summarized is shown in Figure 1. Essentially, this figure illustrates how a number of groups of SMEs varying over some demographic describe the terms "easy", "medium", and "difficult" for shooting a target (in combat or on target range) with a rifle. One interesting outcome of this analysis was that over virtually all weapons systems evaluated, the SMEs with combat experience consistently ranked shots made "in combat" as being more difficult (i.e., having lower ranges) than SMEs without combat experience. With respect to Figure 1, for example, SMEs with combat experience characterized an "easy combat" shot with rifle as having a range of 42m. On the other hand, SMEs without combat experience characterized the same shot as having a range of 93m. These types of discrepancies were consistent over a number of different weapon systems (e.g., machine guns, grenade launchers, etc).

Table 1 shows an example of the third type of data summarized. In this case, SMEs were asked to rank order the factors the considered to be the most influential in selecting a target. Interestingly, at the end of the entire data collection exercise, many SMEs commented that ranking these factors "on paper" (as in Table 2) versus considering them in visual forms (see Section 2.2) could lead to dramatically different results.

Open Field	Urban Canyon	Close Quarter	
4.2	**4.4**	**3.4**	Amount and/or duration of your exposure
2.4	**2.2**	**3.4**	Distance to Target
5.0	**5.2**	**4.6**	Visibility/Exposure of Target (smoke, dark, cover/concealment)
3.6	**3.4**	**4.4**	Target's weapon or role in unit (rifle, RPG, MG, leader, sniper)
1.8	**1.9**	**1.8**	How well Target is placing fire? Who is Target firing at?
5.4	**5.2**	**5.2**	Speed/direction Target is moving
5.6	**5.7**	**5.2**	Number and proximity of Targets relative to one another
			Other:

Table 2. Average over ALL SMEs with Combat Experience

2.2 Drills and AARs with Scenarios

KA exercises using scenarios presented in a slide format were divided into two groups: Open Field and MOUT. These slides were generated by first person shooter computer games that focus on squad and team combat. While there has been some research in using commercial off the shelf (COTS) computer games to support a variety of needs in the military training community [6][7][8], the use of computer games as knowledge acquisition tools is a novel addition to this body of research. Also, in contrast to [9] [10], the use of computer games is a novel approach to KA for human behavior representation (HBR) in military simulations.

2.2.1 KA Process for Open Field

We developed the Open Field slides from a Hasty Attack exercise [11]. After the SMEs had set up their Hasty Attack, we showed them a variety of slides explaining how we set up the scenario and then proceeded to show them slides (snapshots and movies) of the scenario. Each of these slides was discussed individually and interactively with the SME as the KA session continued. So, for example, we would show a SME a slide like that seen in Figure 2 and ask the SME to prioritize the targets according to how he would engage the targets. For this scenario, the five SMEs used in this part of the study, responded as shown in Table 3.

SME	Target Priority	Comments
2	MG, Rifle, Officer	Officer is not as important once firefight has begun because everything is in turmoil
3	MG, Rifle, Officer	MG is biggest threat and Rifle is next closest
7	Rifle, MG, Officer	Since Rifleman is placing fire on me, he's a big threat. MG is next biggest threat, also requires a smaller adjustment to engage him than it does to engage Officer.
8	MG, Rifle, Officer	<no comments>
9	MG, Rifle, Officer	It's really a toss up. As Tm Leader, I would assign 2 guys on each.

Table 3. SMEs Target Prioritization Reponses to Scenario Shown in Figure 2

While one SME (SME 7) of the five selected a different target as his first engagement, the target priority responses were fairly consistent among the SMEs. Generally, they considered the Machine Gunner (MG) to be the biggest

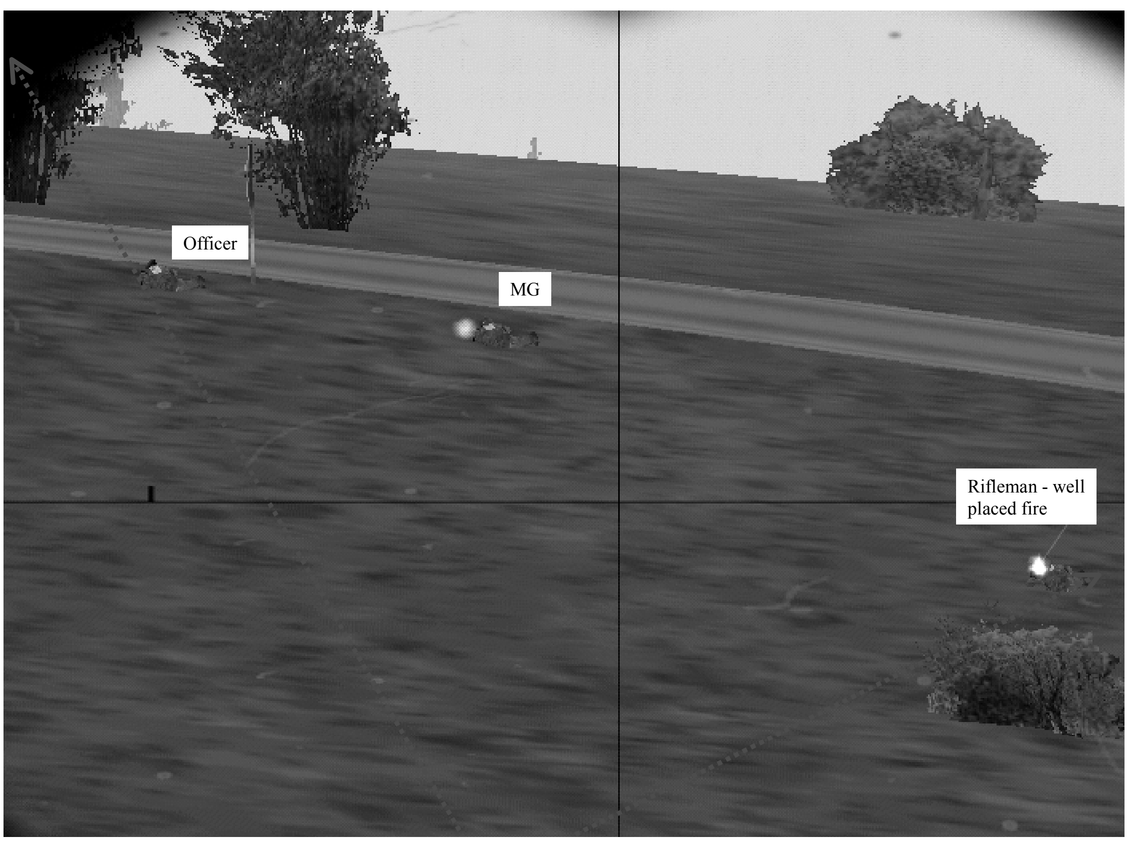


Figure 2. Example of Open Field Target Prioritization Exercise

threat and everybody agreed that the Officer was the least threatening target. For the most part, even the rationale was similar at a gross level. SMEs tended to prioritize according to who was putting effective fire on them.

In addition to the information acquired on our initial set of factors, this methodology helped us to acquire other factors that we had not considered in our initial set. For example, from discussion generated by this single slide, SMEs added the following two factors to our initial set:

1) **SME 2** mentioned that: "*Officer is not as important once firefight has begun because everything is in turmoil*".
2) **SME 7** offered rationale for second target as: "*it requires a smaller adjustment to engage him than it does to engage Officer*".

In all, we collected weapons firing behavior rules for over 50 slides depicting Open Field combat situations. What these slides revealed were general priorities and tradeoffs amongst some of the factors. What these slides did not capture was precisely at what point those tradeoffs occur.

2.2.2 KA Process for MOUT

From experience gained through Open Field KA exercises, we refined our methodology for MOUT KA sessions. Essentially we had identified two flaws that could be improved. The first flaw was that we were giving the SMEs too much time to analyze the scenario. SMEs with combat experience expressed the immediacy with which one under the stress of combat will react. This time constraint was not realistically or even remotely considered in our initial methodology. Secondly, as seen in the responses of the SMEs in the Open Field scenarios, SMEs did not agree with the assumption that they would know which targets were shooting which weapons. They indicated that sometimes a soldier would be able to distinguish this, but that we had oversimplified the information by attaching a label. With this feedback, we improved our approach prior to beginning the MOUT KA portion of our investigation.

In the MOUT KA sessions, we continued to use scenarios presented in slides, but this time we presented the slides in a rapid drill fashion. That is, a SME was given 4 seconds to select a target, at which time the slide show would progress to the next scenario in the sequence. This better represented the immediacy of response required by SME and added a little stress to the task.

Also, in this drill session, we did not provide the SMEs with additional information on targets' weapons or roles. We simply asked the SME to select a target based on the visual cues available in the graphic. To give the SME a way to respond quickly, we annotated the targets with colored arrows and asked the SME to indicate the preferred target by its associated arrow color. One example of a MOUT KA drill slide may be seen in Figure 3. In this slide of the drill, the SME was asked to prioritize targets shown.

Figure 3. Example 1 of MOUT Target Prioritization Drill

Analysis of this slide reveals that some the factors that may be influencing a SME's decision include:

- Targets' distance (i.e., Orange closest, Green next closest, Yellow furthest)
- Targets' actions/firing status (i.e., Yellow prepared to fire, Green not poised to fire, Orange not poised to fire)
- Targets' visibility due to camouflage, lighting, and distance (i.e., Orange/Green easier to see than Yellow).

SME responses in this case are reported below in Table 4.

SME	Target Selected in Drill	AAR/Comments/Target Selection Rationale
1	ORANGE	nearest threat; would shoot near to far (Orange, Green, Yellow). Weapon of choice would be a pistol caliber type long gun (e.g., M5) or rifle cartridge short gun (e.g., FP90 or M-16).
4	YELLOW	firing and Orange/Green are reloading
5	YELLOW	Yellow is about to engage, then target Orange, then Green. Would prefer to have SAW, but if had rifle, would use double tap mode. Would re-engage target until he goes down.
10	YELLOW	looking at me, prepared to fire
11	ORANGE	Closest. Can't see that Yellow is threat.
12	GREEN	saw Green first. Probably should have picked Yellow - weapon is up/engaged.

Table 4. SMEs' Target Prioritization Reponses to Scenario Shown in Figure 3

Using a simple form of knowledge acquisition, a manual or very general heuristic acquired through a SME interview, an engineer modeling target selection could likely develop a target selection based on proximity Applying this heuristic, in a scenario like that shown in Figure 3, would yield a response of "Orange". According to the data presented in Table 4, this response would be an accurate replication of true human behavior approximately 33% of the time[1]. However, a more thorough KA effort perhaps one based on observation or even introspection with more context, would additionally reveal that sometimes a SME might assign higher priority to the target that is closer to engaging, even though that target might not be closest in proximity. According to the data presented in Table 4, applying this heuristic would yield a response of "Yellow", and this response would replicate actual human behavior approximately 50% of the time. However, only a KA effort based on observation would result in a heuristic that would pick "Green", like SME 12 did. This is because SME 12, if given opportunity to deliberate about his response, would have selected "Yellow" (as evidenced in his AAR). But, instinctively or reactively, SME 12 selected "Green" as his first target. This illustrates the idea that KA methods based on observation in a naturalistic environment (or even something that simulates observation in a naturalistic environment) may not always produce the best response, but will produce the most probable response. In other words, even though SME 12 should have picked "Yellow" (better response), he actually picked "Green" (gut reaction).

This example illustrates how HBR models can benefit from the use of performance data to make the training scenario more realistic for the trainee. Ironically, in the last case, the reason that the IC model would be more consistent with real world data is because it would capture and model mistakes like poor target selections as well as optimal behaviors.

After the slide had displayed for 4 seconds, a new slide (e.g., Figure 4) would be presented. So, to review the format of the drill, a slide such as Figure 3 would display for four seconds, the SME would indicate which color arrow was associated with his highest priority target, and then the next slide in the sequence (Figure 4) would be presented to the SME. This process would iterate over all 33 slides in the drill. Since, in the initial rapid drill, SMEs would simply respond with the selection of a target, the drill exercise in the KA session only required:

$$33 \text{ (slides in drill)} * 4 \text{ (sec/slide)} = 2.2 \text{ minutes.} \qquad (3)$$

Analysis of the scenario in Figure 4 reveals that some of the factors that may influence a SME's decision could include:

- Targets' proximity to cover/concealment (i.e., Green closer to bus than Orange)
- Targets' visibility as a function of lighting and camouflage with environment (i.e., Orange slightly more visible than Green)
- Targets' firing status/action (i.e., Orange prepared to fire at IC, Green's actions less discernible due to visibility).

In this case, however, and in contrast to case presented in Figure 3, all SMEs consistently picked the same target (i.e., Orange). However, rationale for picking this target, as evidenced in Table 5, varied slightly.

[1] This example is for illustrative purposes only. It is important to recognize that the sample size in Table 4 is small and therefore, possibly not representative of true population.

Figure 4. Example 2 of MOUT Target Prioritization Drill

SME	Target Selected in Drill	AAR/Comments/Target Selection Rationale
1	ORANGE	Would engage right to left out of habit/training
4	ORANGE	Stands out more, other guy doesn't seem to be pointing gun
5	ORANGE	More visible
10	ORANGE	Pointing at me
11	ORANGE	Green is looking to right and Orange is look and pointing at me
12	ORANGE	Pointing at me

Table 5. SMEs' Target Prioritization Reponses to Scenario Shown in Figure 4

The SME's rationale would be discussed in the AAR part of the KA session. Depending on the scenario, the AAR could also consider weapons selection, sector assignments, and mode of fire (e.g., double tap, single shot, controlled pairs, etc). Sometimes this additional knowledge was acquired verbally and other times it was presented as a specific alteration to the scenario and discussed as part of AAR. For example, in the AAR associated with Figure 4, additional weapons firing information acquired verbally included:

1) **SME 5** mentioned that: "*Would prefer to have SAW here, but if using M4 would fire with double tap on both targets*".
2) **SME 7** mentioned that: "*Would fire using 3-round burst because M4s not always effective in generating kills*".

Alternatively or as a follow up, we could acquire additional information by altering the scenario as demonstrated in Figure 5. Thus, we could complicate the

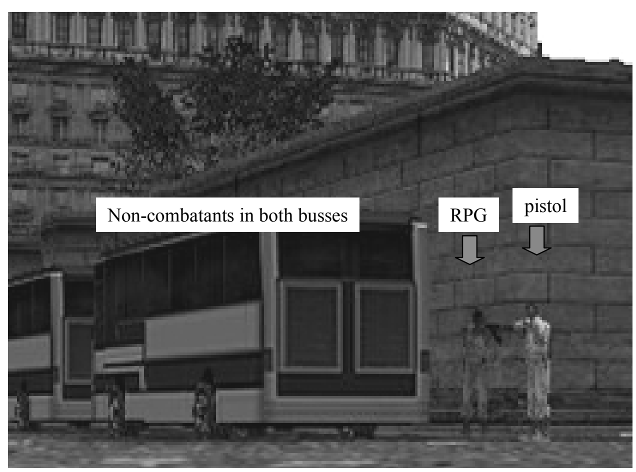


Figure 5. Example MOUT Target Prioritization AAR Session (for Slide in Figure 4)

scenario to determine how the new information would change the SME's response. Though not time-stressed as in the drill, this still proved to be a valuable technique for acquiring new knowledge. Table 6, for instance, shows

SME #	Target Selected		AAR Comments and Rationale for NEW Target Selection
	Drill Fig 4	AAR Fig 5	
1	ORANGE	ORANGE	Would still shoot Orange first. But if I was in a building (or similar type cover that could be defeated by the RPG), then I would shoot RPG first.
4	ORANGE	ORANGE	Would still shoot Orange first since distance is close enough for pistol to be effective.
5	ORANGE	ORANGE	Would still pick Orange as first target. But, because on non-combatants in bus, would definitely not want to use SAW, like before. But, if I was using an M4, I would still shoot double taps.
10	ORANGE	GREEN	RPG becomes priority. Would fire rifle with single shots, since non-combatants near-by.
11	ORANGE	GREEN	Since non-combatants in busses, would use single, well-aimed shots. RPG is higher priority because at this range, Orange (pistol) is not as much of a threat. If there were no civilians in busses, I could assign a 203 gunner to both targets.
12	ORANGE	GREEN	If he's pointing at me with RPG, Green would be my priority. But, if Green is not pointed at me, I would still shoot Orange. Also, if I'm in cover (that could be defeated by RPG), the I would assign first priority to Green (even if Green was not pointing at me).

Table 6. Weapon Firing Data as Function of Changes Shown in Figure 5

how SMEs' responses changed as a result of adding the new information in Figure 5. Gainfully, these changes in response can be directly attributed to the specific changes in the factor settings. This proved to be an efficient method for acquiring a lot of usable knowledge from SMEs in a limited amount of time.

3. Results and Analyses

Research report [12] documents the complete set of scenarios and acquired data. Overall, of the scenarios presented in the Open Field KA and MOUT KA sessions, at least one SME's selection of targets differed 59% and 55%, respectively, of the time. In other words, approximately 40-45% of the time all SMEs selected the same target. This provides at least some support for our initial hypothesis suggesting that large portions of the decision space can be covered by general heuristics common to a majority of SMEs. In those regions of the decision space that were more influenced by individual differences, the methodology we employed helped to identify what these individual preferences were and in what state space they were likely to be important factors.

One general heuristic that was supported by this data collection effort, for example, was the practice of maintaining sectors of fire. Across scenarios, both Open Field and MOUT, SMEs were religious about engaging targets in their assigned sectors. This discipline was maintained even when we presented the SMEs with scenarios designed to sway their judgment as shown below in Figure 6.

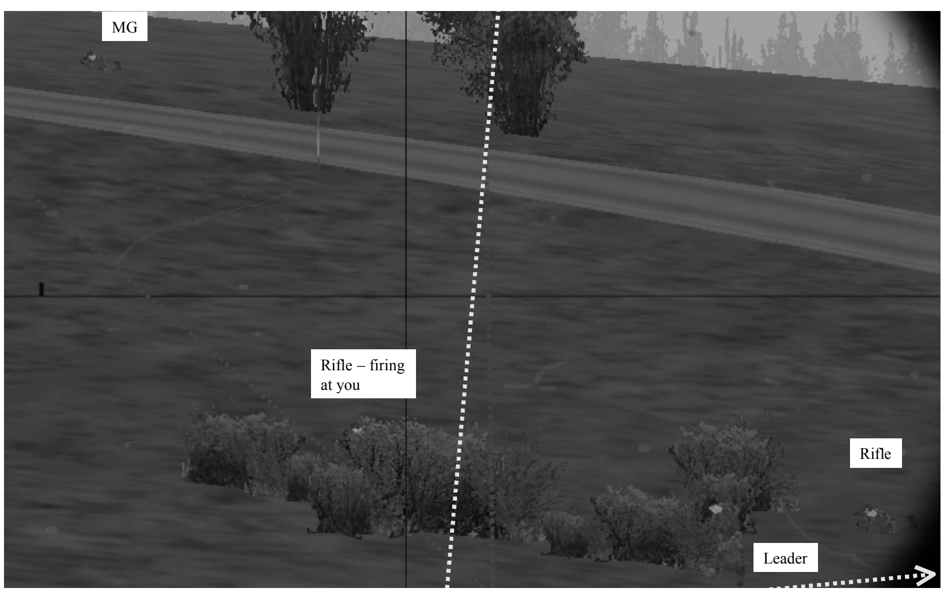


Figure 6. Example of Scenario to Test SME's Resolve to Maintain Assigned Fire Sector

Even in a scenario such as this, where the targets in Blue sector present a more imminent threat to the SME, the SME assigned to Yellow sector will maintain his target priorities in accordance with that sector's boundaries.

On the other hand, any one of the slides already presented in this paper and many others presented in final report [12] offer examples of where individual differences or preferences are apparent in a SME's decision. Whether this decision was related to target selection (as in Figure 3) or related to weapon selection or firing mode (as evidenced in Figure 4), the data demonstrate that responses across SMEs could be different. Or, sometimes the responses were consistent, but the motives behind the responses were different. For types of analyses performed with IUSS, not all of this information was useful. For example, the IUSS simulation doesn't support firing single shots versus double taps and it is not important to model under what conditions a SME would prefer one to another. But, particularly in training, where we strive to present realistic opponents that hopefully maximize training transfer and minimally do not promote negative training [13], we believe that these subtleties in IC behavior are important.

In closing, while we have no data to precisely compare this methodology with other means of KA (e.g., pure introspection, observation, etc.), the method seemed to be a relatively cost efficient way of capturing a lot of useful information in a relatively short period of time. SMEs who had been through KA sessions in the past appreciated the visual cues and commented positively on the organization and structure of the session. Finally, we believe that the visual cues helped to maintain consistency between the "mental models" of the SMEs and the engineers.

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