Proceedings of the 2016 Winter Simulation Conference
T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

ACTIVE SHOOTER: AN AGENT-BASED MODEL OF UNARMED RESISTANCE

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ABSTRACT

Mass shootings unfold quickly and are rarely foreseen by victims. Increasingly, training is provided to increase chances of surviving active shooter scenarios, usually emphasizing "Run, Hide, Fight." Evidence from prior mass shootings suggests that casualties may be limited should the shooter encounter unarmed resistance prior to the arrival of law enforcement officers (LEOs). An agent-based model (ABM) explored the potential for limiting casualties should a small proportion of potential victims swarm a gunman, as occurred on a train from Amsterdam to Paris in 2015. Results suggest that even with a miniscule probability of overcoming a shooter, fighters may save lives but put themselves at increased risk. While not intended to prescribe a course of action, the model suggests the potential for a reduction in casualties in active shooter scenarios.

1 INTRODUCTION

Mass shootings unfold quickly and are rarely foreseen by victims. Mass shootings have occurred at a variety of locations including military installations and government buildings, public spaces including nightclubs (Orlando, FL), movie theaters (Aurora, CO), shopping malls, workplaces, religious facilities, and educational campuses (Littleton, CO; Blacksburg, VA; Newtown, CT).

The difficulty of preventing mass shootings has led to increased active shooter training. Law enforcement agencies have revised response tactics for active shooter situations following the Columbine high school shooting (Police Executive Research Forum 2014) and employers and public safety organizations have developed protocols including "Run, Hide, Fight" or "Avoid, Deny, Defend" for individuals in an active shooter situation. The implementation of these tiered strategies may benefit the individual who successfully flees or hides, but may subsequently put someone else at greater risk (e.g., by monopolizing a secure hiding spot) and may not substantively reduce the overall number of casualties in a mass shooting scenario.

In 2015, a presumed mass shooter on a Thalys train from Amsterdam to Paris was subdued by the rapid action of several men who engaged in hand-to-hand combat with the gunman. Two of the men were seriously injured—one shot, one severely cut—but both survived. No one was killed and the gunman was captured, despite being armed with an AKM rifle, a Luger pistol, and a box cutter.

Researching mass shootings presents obvious methodological challenges: conducting an experiment in which participants believe they are actually facing potential death from an active shooter is ethically intractable and could lead to actual harm (e.g., attempts to subdue shooter). While tactical drills such as those used by LEOs and military can simulate the mechanics of facing an active shooter, the explicit knowledge that one is in a simulation likely dampens neurophysiological responses and would hopefully preclude participants from improvising a lethal response against the individual acting as the mass shooter.

Examining historical mass shootings is a valuable research technique, but there are known limitations on eyewitness accounts and certainly no possibility of altering the historical scenario in an attempt to influence outcomes. Agent-based modeling (ABM) is a logical choice to explore the potential impact of intended targets' behavior when encountering an active shooter since it harms no human subjects, can explicitly encapsulate behavioral rules, and offers the possibility of running the model under altered conditions to investigate outcomes. The present research uses ABM to investigate the degree to which the rapid action of a few individuals who physically confront a shooter might potentially limit the casualties in mass shooting scenarios.

2 BACKGROUND

2.1 Active Shooters and Mass Shootings

From 2000 to 2013, the U.S. FBI reported 160 active shooter incidents in which 486 were killed and 557 wounded, excluding the shooters (Blair and Schweit 2013). Any attempt to tabulate shooting incidents is ultimately definition-dependent and definitions are debated. The FBI defines an active shooter as "an individual actively engaged in killing or attempting to kill people in a populated area," noting that "implicit in this definition is the subject's criminal actions [must] involve the use of firearms." The definition of a *mass shooting* is based on that of mass murder, defined as four or more individuals killed during the same incident. An active shooter scenario may or may not qualify as a mass shooting, then, as fatalities depend on both the lethality of victims' wounds and relatively distal variables like the availability of advanced trauma care following the shooting. A potential drawback of using the mass murder definition is that it relies on quantified fatalities, so an active shooter incident in which many people are shot but fewer than four perish does not meet the threshold of mass shooting.

The FBI notes that both law enforcement and citizens have the potential to affect the outcome of an active shooter event (Blair and Schweit 2013). In the 104 active shooter incidents from 2000 to 2012, the shooter was stopped by victims in 17 incidents, by police in 32 incidents, and in 55 incidents, stopped on his own accord, committing suicide in 44 cases, surrendering in 6 cases, and leaving in 5 cases. (Blair, Martaindale, and Nichols 2014). Of the 17 incidents in which victims stopped the gunman, in 3 cases the active shooter was shot by armed victims.

2.2 Prior Agent-Based Models

Hayes and Hayes (2014) created several ABMs of mass shooting scenarios to test specific provisions of Senator Dianne Feinstein's proposed legislation to limit certain specific types of firearms. A model of the Aurora, CO movie theater shooting in 2012 and a generalized indoor model found that only a reduction in a firearm's rate of fire would have likely reduced the number of casualties in the Aurora shooting (Hayes and Hayes 2014). A school shooting model exploring the presence of armed school law enforcement officers (LEOs) and staff carrying concealed firearms suggested that either intervention would likely decrease response time in confronting the shooter and reduce casualties, though the model assumes that the shooter would be instantly neutralized upon entering a room in which a single armed individual is present (Anklam et al. 2015). This assumption may be overly optimistic in light of studies of shooting performance of law enforcement officers (Lewinski et al. 2015; Vickers and Lewinski 2012). Anklam et al. (2015) conclude that reducing the time-to-intercept of an active shooter will likely reduce casualties, but their school shooting model considered intercept possible only by armed individuals, with no distinction between LEOs and civilians.

No ABMs could be located that examined the potential role of unarmed resistance in an active shooter scenario.

3 METHOD

3.1 Agent-Based Model

Developed using NetLogo (Wilensky 1999), model implementation followed Wilensky and Rand's (2015) ABM design principle: start simply and build toward the question of interest. A crowd of agents is distributed on an open landscape (e.g., a large outdoor concert or rally) with no possible cover or concealment. Agents are unaware that a shooting is about to occur. A randomly-located shooter begins firing on the closest targets. Once the shooting begins, most agents flee from the shooter at their running speed. On reaching the outer perimeter of the simulation, fleeing agents are presumed safe and can no longer be targeted. A small proportion of agents, if close enough, try to tackle and subdue the shooter. The simulation ends if the shooter is subdued, when the shooter hits every possible target, and/or all targets have escaped. For parsimony, a fired shot can hit only one victim, no victim can be hit twice, and no lethality determination is made due to the many factors affecting outcomes of gunshot wounds.

3.2 Agents

Population. The agents in the current model possess a normally-distributed running speed sourced from the Hayes and Hayes (2014) ABM of active shooter scenarios: the distribution has a mean of 3.9 m/s and standard deviation 2.7 m/s. Agents are also assumed to have a cognitive delay required to recognize and process that a shooting has begun, after which they immediately run away from the shooter. While actual cognitive delay would likely differ for each individual, in the current model it is a constant such that the entire population simultaneously realizes that a shooting has begun. This parameter is user-adjustable and can be disabled if desired (i.e., set to 0 seconds).

Fighters vs Fleers. Some proportion of the agents are fighters. This proportion is set by the user and is expected to be very small relative to the population. Instead of fleeing from the shooter these individuals, like the individuals who subdued the gunman on the Thalys train, will attempt to tackle the shooter if/when they are close enough. Whether these individuals have military or law enforcement training or are simply extreme altruists is an open question beyond the scope of the current effort. The model simply assumes that some number of people – however few – might choose to endanger themselves in response to an active shooter. In this model, fighters run toward the active shooter, putting themselves at greater risk by closing the distance and increasing the likelihood of being hit by a consequently more accurate shot. The user sets the probability with which a fighter struggling with a shooter is likely to overcome the shooter on each tick. This is a global parameter: if the user gives a fighter a 1% chance of overcoming the shooter and three fighters struggle with a shooter, each fighter has precisely a 1% chance per tick of overcoming the shooter. In other words, there is currently no additional advantage when multiple fighters conduct a swarm attack and struggle with the shooter simultaneously, though this will be explored in future model extensions.

Shooter. User-adjustable parameters can be set to account for armament (magazine capacity and firearm effective range) and shooter ability (accuracy and field of view for targeting). For parsimony a shooter always targets the closest agent in (1) firearm effective range and (2) field of view, and will fire one round per second (tick). Firearm rate of fire is frequently debated. For parsimony, one round per second is fired in the current model. This rate of fire likely overestimates most shooters' ability to accurately target and fire but could represent indiscriminate firing into a crowd.

Whether or not the target is hit is probabilistic and depends on three factors: distance between shooter and target, the user-adjustable accuracy parameter, and the firearm's effective range. Firearm effective range is implemented in the current model as the range at which a 100% accurate shooter hits a human-sized target 50% of the time. This parameter allows users to approximate the type of firearm employed: most shooters will be accurate at greater distances with rifles than pistols and range can be set accordingly. The user-adjustable accuracy parameter allows the user to account for the human component of shooting accuracy. At 1.0, the shooter is 100% accurate at point-blank range and 50% accurate at the firearm's effective range. In actual firefights involving LEOs, many rounds miss their intended targets even at relatively close ranges, so a 1.0 accuracy setting is likely highly unrealistic, but is nevertheless available to the user (Lewinski et al. 2015). If a fired round misses the intended target, it continues traveling and may hit another agent if that agent is in the round's trajectory. In dense crowds, therefore, even an inaccurate shooter is capable of inflicting substantial casualties. The shooter continues to target and fire on each tick, either until subdued by fighters or until all potential targets have reached the perimeter of the landscape. In the current version of the model, the shooter does not move to pursue targets and remains in a single location for the duration of the simulation.

3.3 Initial Setup

The user adjusts the population size such that the desired physical crowd density is achieved. Density is important because it affects (1) the number of possible targets in the shooter's range and vision and (2) the likelihood that a shot that misses the intended target will wound another agent in the round's trajectory. The user also sets model parameters described above.

3.4 Model Action

On the first model tick, the shooter "activates," targeting the nearest individual in his field of view and firing. (To conceptualize field of view, imagine sweeping a wide-beam flashlight from side to side – everything in the cone made by the flashlight beam is in the field of view.) On each subsequent tick, the shooter takes the same action: target, then fire. When the shooter targets, he turns to directly face the targeted individual, changing his field of view. A shooter cannot see behind himself and can only see what is in his field of view. After the shooting begins and the cognitive delay time has elapsed, most agents will begin fleeing from the shooter. Fighters present will run toward the shooter and try to tackle him if close enough to reach in less than one second, a distance that varies depending on a fighter's unique running speed.

When a fighter reaches a shooter, a struggle begins and the shooter shifts his attention to the fighter. In reality, the likelihood of either a fighter overcoming a shooter or a shooter overcoming a fighter will depend on a substantial number of variables such as prior combat training, physical strength, weaponry, and assistance from others. As each of these can be vigorously debated, the user sets probabilities of success for both the shooter and the fighter. Probabilities are implemented on a per-tick basis. Calibration data for these probabilities could not be located, so it is suggested that the shooter should have a very high probability of overcoming the fighter (perhaps because the shooter also carries weapons intended for close-range combat, whether pistols or bladed weapons) and the fighter should have a low probability of overcoming the fighter due to the relative disadvantage in armament. Fighters who fail become victims (i.e., are wounded and incapacitated for the remainder of the simulation).

3.5 Model Output

In addition to a visual view of the unfolding scenario, the model tracks the number of rounds fired, the number of rounds that strike individuals, and the number of fighters struggling with a shooter at each tick.

3.6 Model Calibration

Parameter sweeps using NetLogo BehaviorSpace examined model sensitivity and differences in outputs. The parameters were varied as indicated in Table 1 and results are discussed in the next section.

Table 1: Model parameters with bold values indicating final stable model defaults.

Parameter	Values	Notes
population	500 1000 **5000** 7500	Agent population
%-who-fight	0.001 0.003 **0.005** 0.010	Percentage of agent population who are "fighters" rather than "fleers"
chance-of-overcoming-shooter	**0.01** 0.05 0.10	Per-tick probability of a fighter overcoming the shooter in a hand-to-hand struggle
shooters	**1**	Number of shooters
shooter-magazine-capacity	**10**	Rounds that can be fired before a magazine reload (shooters have unlimited magazines)
firearm-effective-range	30m **50m** 70m	Range at which a 100% accurate shooter will hit target 50% of the time; used in hit probability
shot-accuracy	0.5 **0.8** 1.0	Human factor in accuracy; combines with firearm-effective-range to determine hit probability of each shot
field-of-view	**180 degrees**	shooter's field of view (see section 3.2)
shooter-chance-of-overcoming-fighter	**0.5**	Per-tick probability of shooter overcoming a fighter in a hand-to-hand struggle

3.7 Verification and Validation

Verification and validation are particularly challenging for the current model and topic. Though mass shootings occur, there is a dearth of detailed publicly available data and a large number of variables and unknowns that affect ultimate outcomes. Hayes and Hayes (2014) validated their model of the 2012 Aurora, CO movie theater shooting by calibrating the model such that, on average, a model run approximated the same number of casualties that actually occurred during the shooting. This is a laudable strategy, but one that is not easily employed in a generalized active shooter model. A shooter's targeting strategy, weaponry, and accuracy are likely to have the greatest impact on casualties, followed by the behavior of intended victims (e.g., do intended victims make themselves easier or more difficult targets?). As mentioned in the introduction, conducting an experiment to test victim response to an active shooter is not practicable; it would be ethically impossible to create a true life-or-death situation in which individuals would respond with potentially lethal force. This model is inspired by the events on the Thalys train and also what is believed to have occurred on United Flight 93 on September 11, 2001, but these situations are extremely rare and ought not be considered representative. Each mass shooting is different, and caution should be employed making generalizations from one mass shooting to another. Subject-matter experts are invited to criticize the assumptions of the current model and suggestions are welcomed. Other modelers are encouraged to replicate or extend the current model.

The current ABM was subject to verification during the process of model construction using unit tests written into model code to ensure that a particular procedure is behaving as intended and that code was adequately debugged (Wilensky and Rand 2015).

Validation requires at least some correspondence between the model's behavior and the behavior of the target system (Gilbert and Troitzsch 2005). At the present stage of this research effort, invoking the oft-cited quote from George Box may prove helpful: "All models are wrong, but some are useful." The validation question, then, rests on whether or not the current model can be useful as platform for exploring the role of intended victims of an active shooter.

4 RESULTS

4.1 Overall

The current model suggests unarmed resistance to an active shooter may reduce overall casualties in an active shooter incident.

With default model parameter settings (as shown in Table 1), the shooter is subdued in 67 percent of experimental model runs and overall casualties are mean 30. This is a substantial reduction in casualties from the no fighter control condition in which mean casualties are 57. In the remaining 33 percent of model runs in which the shooter is not subdued, mean casualties are increased only slightly to 63, with a greater share of fighters among the casualties as a result of putting themselves in harm's way. Figure 1 plots casualties by simulation end time in 500 model runs in both the control and experimental conditions. The number of casualties sustained in each incident is directly related to time since the shooter has a sustained rate of fire of one round per second. In the experimental runs in which the shooter is subdued, mean time elapsed is 100 seconds, far less than in the control condition in which the simulation typically concludes at 255 seconds after which all remaining victims have escaped the perimeter.

Importantly, default model parameters were selected to be as conservative as possible, and the model and code are available upon request from the author for any user who wishes to set the parameters less or even more conservatively. In the absence of empirical data sources to calibrate the model, users are encouraged to consult relevant subject matter experts in choosing parameter settings.

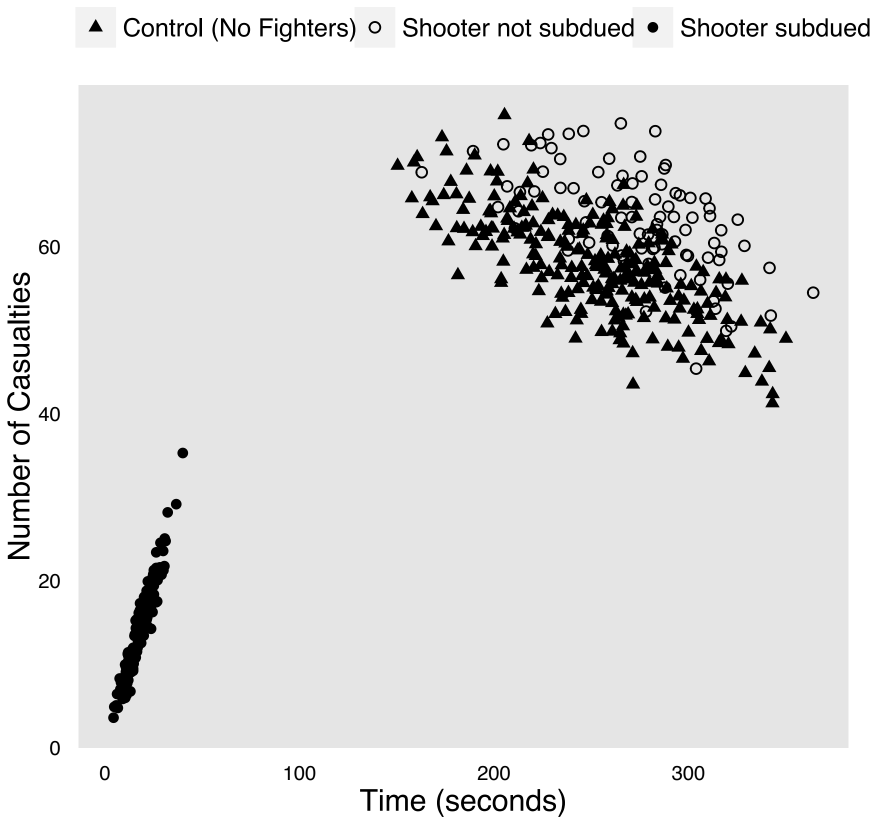

Figure 1: Casualties by simulation end time in control and experimental conditions (plot displays a random sample of 500 of 2000 model runs for ease of visibility).

4.2 Flee vs. Fight Proportion

Unsurprisingly, the greater the proportion of fighters in the population, the more likely the shooter will be subdued. If too few fight, there is little chance of overcoming the shooter. Varying the proportion of the population that fights changes the likelihood of overcoming the shooter. If only 0.1 percent fight, virtually no model runs result in subduing the shooter; if 0.4 percent fight, the shooter is subdued in about half of model runs, and if between 0.8 and 1 percent fight, the shooter is subdued in nearly all model runs.

4.3 Other Parameters

The current effort did not test rate of fire, since the Hayes and Hayes (2014) ABM demonstrated that reducing rate of fire would likely reduce casualties in an active shooter scenario. No appreciable difference in outcomes occurred by varying magazine capacity, since reload times of ~1 second (note that such a rapid reload time is possible by using a technique known as a "speed reload") do not substantially reduce overall rounds fired. (Reloads may, however, present ideal opportunities to engage a shooter, though this was not tested with the current model.)

Firearm effective range was varied between 30 m, 50 m, and 70 m to explore potential differences between the use of pistols and rifles, the latter being more accurate at greater distances. Despite extensive media coverage of the use of semiautomatic rifles in mass shootings, the majority of mass shooters to date have used pistols. In runs in which the shooter is subdued, casualties are only slightly increased with the use of more accurate firearms since the majority of casualties occur initially at close range. When the shooter is not subdued and can continue firing on fleeing victims, casualties increase almost linearly, as might be expected.

4.4 Qualitative Observations

The greatest concentration of casualties will occur at the beginning of the simulation since victims only begin fleeing after realizing what is happening. Shooters will almost always possess an informational advantage over intended victims because only the shooter knows when and where he will open fire and his targeting strategy (if anything other than random or based on proximity).

Viewing the model visualization in real time illustrates that individuals who attempt to attack the shooter from a great distance are at a serious tactical disadvantage, particularly if they have a slow approach speed. By reducing the distance between themselves and the shooter, they increase the likelihood that they will be shot. This may suggest pursuing an avoid (run) or deny (hide) strategy unless structural features of the environment can shield would-be fighters from the shooter's sight and fire (e.g., rooms, corners, or other cover or concealment) and facilitate getting close enough for hand-to-hand combat with the shooter. Another important interpretation of this result is that LEO entry teams, moving slowly toward the shooter's location, would potentially be at great risk should a shooter stage an ambush.

5 DISCUSSION

5.1 Fighters will likely save lives but put themselves at increased risk

Attention is a scarce commodity, and every second that an active shooter struggles with a fighter is a second that he is not able to effectively target and fire upon another victim. The "Run" and "Hide" prescriptions are intended to occupy the shooter's time and attention: time spent by a shooter searching for available victims is time for law enforcement to arrive on the scene, form an entry team, and sweep for the shooter. Unfortunately, as suggested by incident reports for the Virginia Tech and Sandy Hook shootings, active shooters encountering harder targets like barricaded rooms will simply move on to softer targets. Further, when potential victims "hide" by huddling together in a room corner with little or no cover or concealment – like most victims at Sandy Hook Elementary – it may be even easier for a shooter to inflict maximal casualties with fewer rounds fired.

It is impossible to calculate precise odds of becoming a casualty in an active shooter scenario, regardless of whether an individual chooses to run, hide, or fight. However, it is the case that there is at least a nonzero probability of successfully overcoming a shooter, as demonstrated on the Thalys train and in 17 of the 104 cases studied by the FBI (Blair, Martaindale, and Nichols 2014). The present model suggests that even with a relatively low probability of success and no combined advantage from a coordinated group attack, overall casualties might be reduced if a small number individuals close enough to fight the shooter fight rather than flee.

5.2 Cautions and Guidelines for Interpretation

An important caveat of this work is that it is not intended to prescribe a course of action for individuals to specifically put themselves in harm's way. Most active shooter training emphasizes "Run, Hide, Fight" or "Avoid, Deny, Defend," and emphasis is placed on the order of those options. Trainees are told to "run if you can," "hide if you must," "fight if you have to," with the acknowledgement that each individual must make his or her own decision and there are no guaranteed outcomes.

However, active shooter training also contradicts prior training for hostage situations and armed robberies, which trained compliance with gunmen's demands to *prevent* violence. In mass shooting scenarios, calm cooperation may result in being shot.

The suggestion that untrained civilians engage armed attackers must be considered carefully. When shooters have been subdued in prior incidents, individuals with some form of combat training—either law enforcement or military—are typically involved. Two of the three Americans who subdued the gunman on the Thalys train had military training and one had just returned from deployment in Afghanistan. But even trained, armed LEOs responding to an active shooter can become victims, as was demonstrated when a shooter armed with a semiautomatic rifle attacked a Planned Parenthood facility in Colorado in 2015. Six of the responding LEOs were wounded and one, Officer Garrett Swasey, was killed. Whether one or more average citizens without training might subdue a gunman requires additional research. Though the principal and school psychologist at Sandy Hook were both killed by gunfire, the shooter was very underweight at only 112 pounds (50.8 kg) despite being six feet (1.83 m) tall. It is certainly *possible* that he could have been subdued in a hand-to-hand struggle had the staff been close enough to physically reach and engage him.

5.3 Limitations

Numerous limitations exist in this preliminary modeling effort.

The model does not give any combined advantage to multiple fighters who swarm attack a shooter. This likely underestimates the probability of success should multiple fighters engage the shooter as occurred on the Thalys train. One fighter might, for example, attempt to control the direction of a shooter's weapon while another fighter attempts to take the shooter to the ground by tackling the shooter's legs. (This type of swarm attack is exactly the technique that is typically emphasized in the "Fight" component of many active shooter trainings for civilians.)

The current model is low-fidelity in a number of respects. Both ballistics and hand-to-hand combat are modeled as probabilities. Additionally, agents, whether fleeing or fighting, do not communicate or interact with one another, nor do they have any cover or concealment in the open environment. Crowd behavior is not accounted for in the current model: faster agents simply run through slower agents.

This model does not address the cognitive and behavioral processes underlying heroic acts or acts of extreme altruism; the assumption is that at least some individuals are capable of such acts and will resist when faced with an imminent threat as in the incident on the Thalys train. The user is free to set the percentage of individuals likely to engage a gunman rather than flee.

Importantly, the current model does not represent ballistics with high fidelity. However, the model approximates shot accuracy and permits rounds to continue to travel beyond their intended target, possibly striking another person in the round's trajectory. Fired rounds do not discriminate, and physics ultimately determines when and where rounds will stop. (This is also relevant when considering armed response to an active shooter: trained LEOs may hit their intended targets 50 percent of the time, so an important aspect of modeling mass shooter scenarios is the potential collateral damage of various potential responses, including casualties by friendly fire.)

The current model also does not represent hand-to-hand combat with any fidelity. Any struggle will depend on the skills of the individuals involved and any weaponry available, either the shooter's or improvised by fighters.

A limitation of the current model is the lack of specific forensic information from prior mass shootings with which to validate the model. Presumably, such information exists but is not accessible by the general public. For example, precisely how close were the Americans to the gunman on the Thalys train in 2015? How close were the principal and school psychologist to the gunman at Sandy Hook Elementary when they confronted him in the hallway and were killed in the 2012 shooting? These are important data for model validation, especially for a higher-fidelity simulation.

5.4 Future Research

The current model serves as a starting point for future research efforts, including testing additional parameter combinations, variables, scenarios, and assumptions.

The notion of rapid collective action should be explored. Specifically, agents could be given the ability to communicate—even rapidly, as reportedly happened on the Thalys train—in making the decision to jointly attack a shooter. It may also be the case that there are only an infinitesimally small number of individuals who would attack an active shooter, but that others would join once that individual begins the struggle. In this sense, agents could be further divided into individuals who would attack, regardless, and a greater number of individuals who attack only when others do, invoking a threshold like Epstein's (2002) model of civil violence or Granovetter's (1978) model of collective behavior.

ACKNOWLEDGMENTS

The authors are grateful to Kenneth Comer for inspiring this modeling effort through his seminar on military agent-based modeling at George Mason University in 2015, to Dale Brearcliffe for comments and discussions on drafts of this paper, and to three anonymous peer reviewers for their thoughtful feedback and helpful suggestions.

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