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SIMULATION OF KNIFE ATTACK AND GUN ATTACK ON UNIVERSITY CAMPUS USING AGENT-BASED MODEL AND GIS

Jing Yang (Sunny) Xi
Wai Kin (Victor) Chan

Environmental Science and New Energy Technology Engineering Laboratory
Tsinghua-Berkeley Shenzhen Institute, Tsinghua University
Shenzhen, 518055, P.R. CHINA

ABSTRACT

While mass shootings in schools plagues the campus security of the United States, China, due to its gun ban, instead deals with knife wielding attackers. Over the past three years, more than 30 stabbings have occurred in school campuses, with hundreds of people being injured or killed. This paper computationally examines the consequences of people's actions during a university campus attack using a combination of agent-based simulation and GIS mapping. Experimental results suggest that when facing an attacker with a knife, people should team up and attempt to subdue the attacker, whereas when facing an attacker with a gun, people should flee the area and wait for law enforcement to arrive if they cannot subdue the attacker quickly.

1 INTRODUCTION

In 2016, according to the People's Daily, the biggest official news outlet in China, there were 26 stabbing incidents in schools that resulted in the deaths of 11 people and injuries of 35 (People.cn 2016). Most of these events occurred in high school and university campuses and all of them involved lone attackers without any accomplices. In recent years, the situation is deteriorating as more deadly school attacks happened. For instance, in April 2018, an knife-wielding attacker killed 9 students and injured 10 more in a school in Mizhi County, Shanxi Province (Sohu.com 2018). Earlier this year, a man with hammer attacked and injured 20 elementary students in Beijing (The New York Times 2019a).

Knife attacks are not limited to China. Two major knife attacks occurred in Paris in 2018, in May and September (BBC.com 2018a and 2018b). Both attacks caused not only injuries but also trauma in society. During the attacks, some people fled while some tried to take down the attacker, for example by throwing pétanque balls at the attacker (BBC.com 2018b)

Although the aforementioned attackers did not have access to firearms, their attacks using knives or other blunt weapons still caused high casualties and great social unrest around the world. In China in particular, knives are the most commonly used weapon in community attacks as gun controls are very strict. While being less destructive than guns and explosives, knives or other blunt instruments can still be dangerous. A recent study shows that stabbing attacks can generate forces great enough to penetrate skin and cause injury no matter what scale the blunt instrument used belongs to, mild, moderate, or severe (Nolan et al. 2018).

The increasing number of knife attacks has increased the security level in many public areas such as train stations, airports, or malls. In China, X-ray scanners have been deployed in all subway entrances to check all bags for dangerous items. In other open locations with dense populations such as universities, it is very difficult to detect or foresee knife attacks. Therefore, it is important to understand the degree of destruction of knife attacks compared to firearm attacks. Preventive and responsive actions can then be designed accordingly.

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This paper compares attack scenarios using either knives or guns on the University Town Campus in Shenzhen, China. As the University Town has no security check points and anyone can enter, there certainly exists a possibility that someone might enter the campus with malicious intents. By simulating the behaviors of the attacker, students, as well as local law enforcement, the detailed flight-or-fight response of the students can be observed and the correlation between the time to subdue the attacker and the decisions that students make can be found. In addition, the agent-based model also compares the differences in people's behaviors during a knife attack and a gun attack.

Section 2 reviews existing agent-based models of mass shootings. Section 3 describes the agent-based model setup as well as other background information crucial to the understanding of the stabbing problem in China. Section 4 contains the details of the experiments conducted. Section 5 discusses the results as well as limitations and future possibilities for the model, and finally, Section 6 concludes the paper.

2 LITERATURE REVIEW

While no agent-based models simulating a knife attack could be found, there are a few models and reports that simulate and study gun attacks or mass shootings. Stewart's (2017) agent-based model simulates the behaviors of the shooter, law enforcement, as well as civilians in a school building. The civilians have two possible choices of hide and run, with hiding being the least optimal one and resulting in the most casualties.

Hayes and Hayes (2014) found that the gun's firing rate, not the type of gun has the most impact on the amount of casualties in their model of a gunman attacking a room in a movie theater. It suggested that in an environment where civilians could run or hide, the addition of more security guards would reduce the amount of casualties; however, this is difficult to achieve.

In 2016, Briggs and Kennedy incorporated the "Run, Hide, Fight" into their agent-based simulation of a mass shooting event (Briggs and Kennedy 2016). Their results suggested that when civilians decide to fight the attacker, they have a possibility to subdue the attacker before law enforcement could arrive, saving more lives but putting themselves at risk. However, this possibility does not increase as more people become motivated to fight rather than run; this phenomenon will be explored in the agent-based model of this paper.

3 METHODOLOGY

3.1 Simulation Purpose

The objective of this simulation is to use an agent-based model to investigate the consequences of students' behaviors during a knife attack versus a gun attack, and to conclude a preferred strategy to minimize casualty if such a strategy exists. For the purpose of this simulation, a student becomes a casualty as soon as it is stabbed or shot once (unlike real attacks where a person can sustain multiple wounds) and is removed from the simulation.

3.2 NetLogo and GIS

The agent-based simulation model is built in NetLogo version 6.0.4 shown in figure 1 (Wilensky 1999; Wilensky and Rand 2015). The GIS and network extensions are used in NetLogo to import a map (based on Baidu Map) of University Town in Shenzhen, China. The GIS map contains 636 nodes and 720 links, with each node connected to at least two neighboring nodes, thus forming a closed network with no cul-de-sacs where agents could be potentially trapped. By using a GIS map, realistic agent movement and shortest-path selection can be simulated.

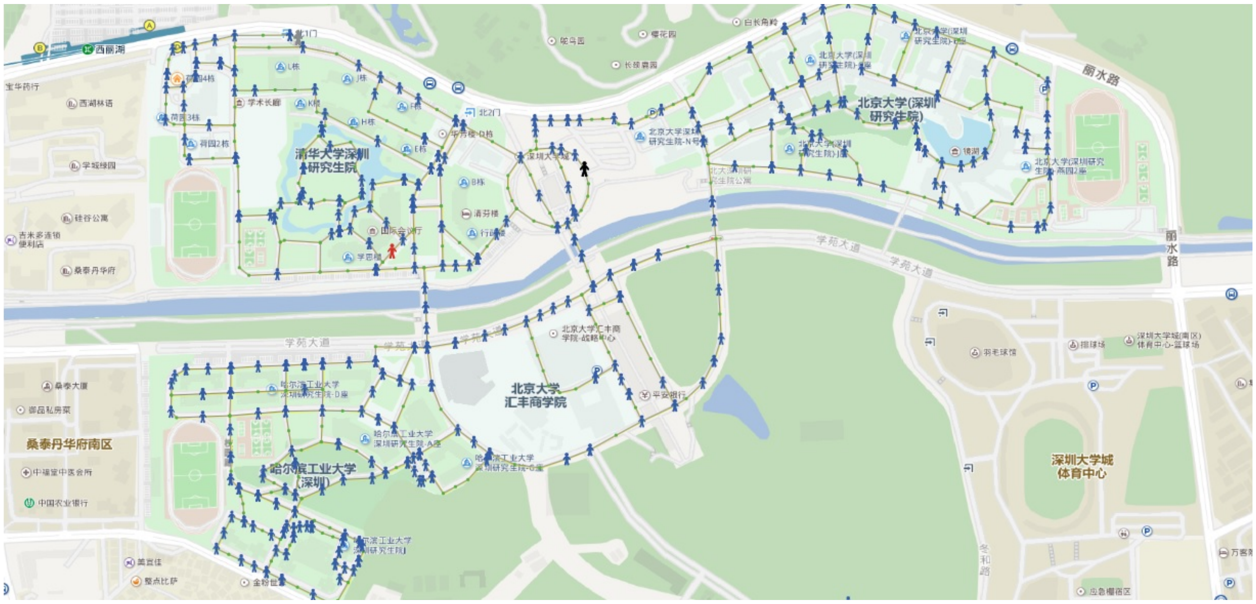

Figure 1: GIS map with agents and background.

3.3 Flow of Simulation

There are four types of agents: student, attacker, security, and police. The initial number of students, the type of weapon the attacker holds, and the initial location of the attacker are all determined by user inputs. Since there are two possible weapons for the attacker, a knife or a gun, there exist two simulation scenarios with slightly different agent rules. These differences can be observed in the flow charts in Figure 2 and Figure 3.

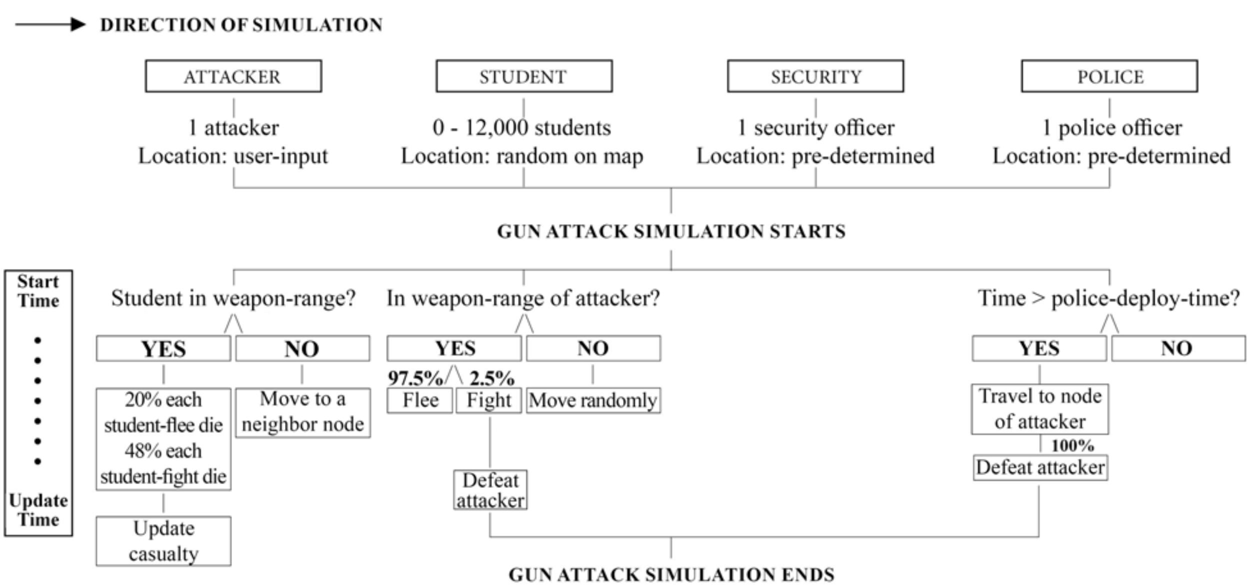

Figure 2: Flow chart: gun attack.

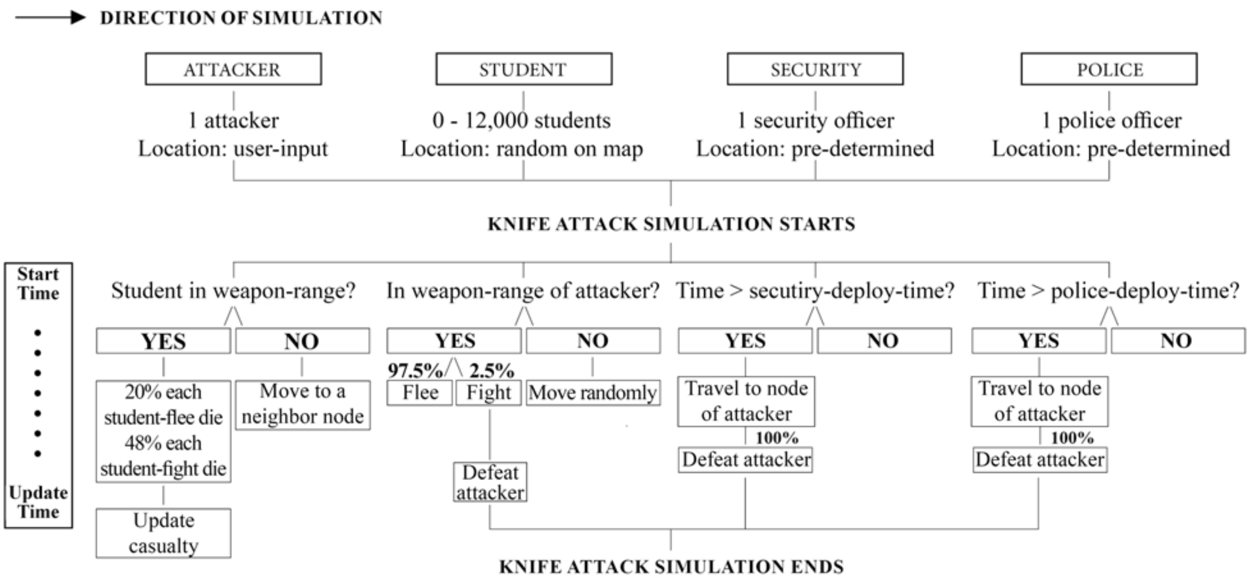

Figure 3: Flow chart: knife attack.

3.4 Agent Rules

Due to lack of forensic evidence, almost no research is done on the reactionary behaviors of students during a school attack, and most of the data available to the public are in the forms of news reports after the incident. Therefore, the parameters in Table 1 are established using a combination of information from media and human behaviors observed from other shooting/stabbing events.

Table 1: Parameters and their values.

Parameter	**Value (gun attack)**	**Value (knife attack)**
weapon-range	1	0.2
student-fight	2.5%	5%
student-flee	97.5%	95%
defeat-attacker	13.1% * number of *student-fight*	19.65%* number of *student-fight*
student-flee-die (accuracy)	20%	0%
student-fight-die (accuracy)	48%	72%
security-deploy-time		Time of first casualty + 2 ticks
security-defeat-attacker	100%	100%
police-deploy-time	Time of first casualty + 3 ticks	Time of first casualty + 2 ticks
police-defeat-attacker	100%	100%

The simulation time is in ticks, with one tick corresponding to approximately 10 seconds in real time. This is calculated from the following steps:

1. From daily observations, estimate the time for a police vehicle in the University Town campus to travel from point A to point B.
2. Locate the same point A and B in the GIS map. Set a speed for the police agent (3 nodes/tick), and record the time a police agent takes to drive from point A to point B in the simulation.
3. Compare the two time data to obtain the ratio between simulation tick and real time.

The following four subsections explain the detailed behaviors and parameter choices for each type of agent.

3.4.1 Attacker

Since most of the previous school attacks were committed by lone perpetrators, the number of attacker in this simulation is set to 1. The attacker is colored red, and its weapon and initial spawn location is set by the user.

In the knife attack simulation, the attacker wields a long and sharp knife, and checks if there are any students within a radius of 0.2. In the gun attack simulation, the attacker wields an automatic weapon with unlimited ammunition and magazine capacity, and checks if there are any students within a radius of 1. These distances are the effective range of a weapon (*weapon-range*) based on the scale in this simulation. Since the attacker is assumed to attack people indiscriminately, instead of targeting specific individuals, it will stay in its current location as long as there are students within its weapon range. However, if there are no targets, it will travel to a random neighboring node and attack students there.

At the beginning of the simulation, the attacker starts to attack students immediately if there are students in its weapon range. The attacker is programmed to move before the students since it has the element of surprise. At the beginning of each time iteration, the attacker would strike each student within its weapon range. The amount of students that are struck down is proportional to the accuracy of weapon used. Accuracy is defined as the percent chance the attacker successfully strikes a student and removes it from the simulation. For a gunman, it can be approximated by dividing the number of people hit over the number of bullets fired (Table 2), under the assumption that each victim was only hit once. The mean and median of these three mass shootings are around 48%, and is set as the accuracy for the attacker in this model (*student-fight-die*).

Table 2. Shooters' accuracies based on data from the three biggest mass shootings in the U.S.

	Number of people hit by direct gunfire	**Number of rounds fired**	**Approx. number of people hit per round (accuracy)**
2012 Aurora, Colorado shooting (Hayes and Hayes 2014)	58	Approx. 110	53%
2016 Orlando nightclub shooting (CBS News 2019)	102	211	48%
2017 Las Vegas shooting (Los Angeles Times 2019)	480	More than 1,100	44%

Theoretically, a similar accuracy for knife attack could be calculated by defining the accuracy of a knife-wielding attacker to be the ratio between the number of wounds inflicted and the number of stabs attempted. Unfortunately, the number of stabs attempted cannot be quantified as easily as counting bullet shells in the aftermath of a shooting. However, in melee range, which is the range this model simulates, a knife is deadlier than a gun since it is much more accurate. For this reason, a knife in this model is set to be 50% more accurate than a gun, at 72% (*student-fight-die*).

3.4.2 Student

The initial amount of students is chosen at either 12,000 or 10,000. 12,000 is the number of full-time registered students at the University Town and the maximum amount of students on campus, while 10,000 is a more realistic estimate of how many students are actually on campus on a typical day. Students are colored blue (Figure 1) and are randomly distributed across the entire campus. They are assumed to be fully grown adults, with no prior combat training and are unarmed. After the attacker has finished with its surprise attack, the surviving students will either flee or fight as observed in many real incidents (e.g., BBC.com 2018a, b).

CCTV footages and videos from previous incidents revealed that almost all of the students attempted to flee from the scene when attacks happened (International Business Times 2013; The Telegraph 2013;). However, in the U.N.C. Charlotte campus shooting event, a hero student Riley C. Howell tackled the gunman as he opened fire in a classroom and pinned him down until the police arrived (The New York Times 2019b). The classroom at that time was having a class named LBST 2213, which usually has an average class size of 40 students (Coursicle 2019). If heroes like Howell exist in every classroom, then the chance of a student fighting back against a gunman can be set at 2.5% (*student-fight*) and the fleeing rate at 97.5% (*student-flee*). Although no probability can be derived for a student fighting a knife attacker from news reports, it is assumed that more students would be willing to fight a knife-wielder attacker as it is easier to stop. In this model, the chance of a student fighting in a knife attack scenario is set to be twice as much as the it is in a gun scenario, at 5% (*student-fight*).

If a student chooses to flee during a knife attack, the student will be completely safe as it will move to a neighboring node before the attacker can attack again (unless the attacker randomly moved to the same node in the next time iteration). The reason is that once it moves to a neighboring node, it is outside of the effective weapon range of the knife and thus can no longer be harmed. However, a student who flees from a gun but is still within the effective range of the gun has a chance of becoming a casualty. In this situation, the attacker is confronted by students who chose fight (if there are any) and would need to eliminate them first before being able to resume his onslaught. The student fighters become the primary focus of the attacker, but bullet ricocheting, piercing, or the attacker missing its intended targets can still injure fleeing students. This chance varies with the trajectory of each bullet and requires extensive ballistics experiments to calculate. For the purpose of this simulation, the chance of becoming a casualty due to collateral damage is set to be a constant at 20% (*student-flee-die*).

In an FBI study of active shooting incidents, 21 out of 160 shooting were resolved when “an unarmed citizen safely and successfully restrained the shooter” (CNN 2016). This probability, 13.1% (*defeat-attacker*), is used in this model to denote the chance of an unarmed student subduing the attacker in the gun attack scenario. Again, this probability for knife attack cannot be calculated due to lack of study. Nevertheless, under the assumption that a knife-wielding attacker is easier to subdue than a gunman, the probability to subdue a knife-wielding attacker is set to be 50% more than its counterpart, at 19.65% (*defeat-attacker*).

The above probabilities of 13.1% and 19.65% are for one fighter per time iteration. However, the more fighters there are, the easier it should be for the students to subdue the attacker. This is also one of the possible extensions that Briggs and Kennedy (2016) discussed in their model. To account for the positive benefits of teamwork, a linear function is introduced that multiplies the probability for one person with the number of people fighting. For instance in a gun attack where there are 2 fighters, each one will have a 26.2% chance of stopping the attacker, and a combined 45.5% chance that at least one of them will stop the attacker during one time iteration. When a student subdues the attacker, the simulation ends.

3.4.3 Security

Security in Chinese schools are armed with non-lethal weapons such as batons, pepper sprays, and long metal sticks (CTV News, 2010; Los Angeles Times 2010). They are capable of subduing attackers with knives or other blunt weapons, but are vulnerable and ineffective against attackers with guns. Therefore, they only respond during a knife attack.

In this model, there is one security officer (colored grey) who will spawn at the front gate of the school before the start of simulation. After the first student casualty has been created in a knife attack, the security officer takes 2 time ticks to learn about the incident and prepare its gears. Then, it will drive to the current location of the attacker by selecting the shortest-path. Once it reaches the attacker, it will immediately subdue the attacker and end the simulation.

3.4.4 Police

The rules of police are almost identical with those of security. However, the police officer (colored black) spawns in the police station and is dispatched for both knife and gun attack. After the first student casualty in a knife attack, its delay time is 2 ticks; for a gun attack, its delay time is 3 ticks, as more preparation is required when facing a shooter. In this current model, struggle between security/police and attacker is not a point of interest, therefore, the chance of the attacker being subdued is set to be 100% (*security-defeat-attacker/ police-defeat-attacker*). However, this probability, as well as the number of security/police can be changed to investigate the interaction between law enforcement and assailant.

4 EXPERIMENTS & RESULTS

In total, 200 knife attack runs and 200 gun attack runs were conducted, using initial student populations of 12,000 and 10,000. During each run, student casualty, time to stop the attacker, and whether or not the students stopped the attacker are recorded. The results are in Figure 4. Since each run ends as soon as law enforcement officers enter the same node as the attacker, the maximum time the attacker can attack is the deploy delay plus the travel time of law enforcement.

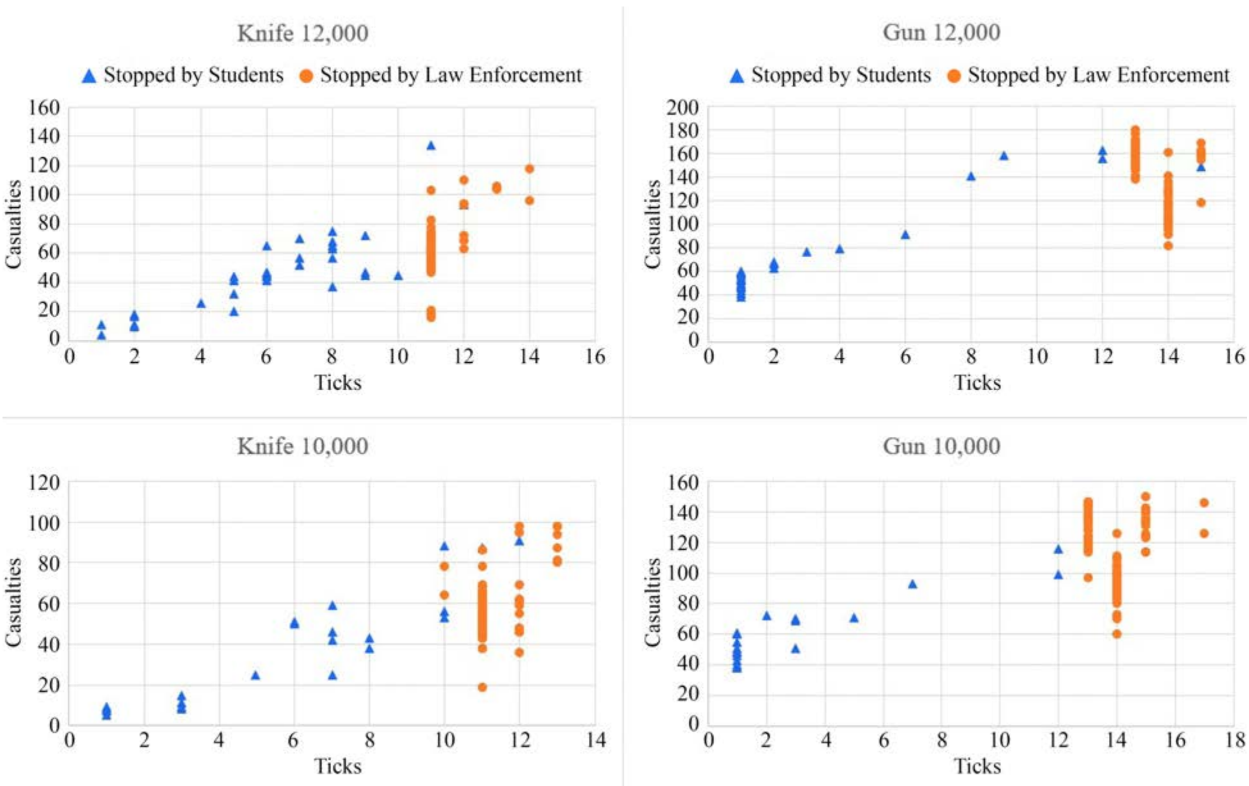

Figure 4: Simulation results plotted in casualties vs. ticks.

5 DISCUSSION & FUTURE WORK

5.1 Discussion

Each plot in Figure 4 contains 100 data points. Each data point is either shaped as a triangle or circle to indicate the attack was stopped by students or by law enforcement, respectively. Simulations with initial populations of 12,000 result in higher initial casualties and steeper slopes than those with initial populations of 10,000. This is to be expected since the more students there are, the more targets for the attacker. In addition, the relationship between casualties and time is seemingly linear for all four plots.

The durations of simulations are distributed fairly equally for knife attacks, as shown in the top left and bottom left graphs. However, in each of the gun attack plot, the region $3 \leq x$ contains at least 75% of the triangle data points. In other words, the scenario where the students are able to subdue the gunman mainly occurs in the first 30 seconds of an attack. In this type of scenario, student fighters can greatly reduce the number of possible casualties; however, if the they are not guaranteed to subdue the gunman in the initial 3 ticks, they should flee and wait for law enforcement to arrive, to prevent themselves from dying in vain.

In general, circle runs have longer durations than triangle runs, except at (15, 149) in the plot of Gun 12,000. This particular run takes the longest despite the fact that students subdued the attacker before law enforcement arrived. Most likely, the random pathing of the attacker is generated in an order that allows the attacker to constantly avoid law enforcement while still being able to attack students. Although random pathing reflects the nature of attackers who attack people indiscriminately without regard of his own survival, in the case of a thoroughly premeditated attack where the attacker is also trying to survive, the attacker would plan an escape route and avoid law enforcement while attacking as many people as he can. This is a possible extension of this model and is discussed more in the next subsection.

Table 3 introduces a variable α, which is defined as the number of times students were able to subdue the attacker before the arrival of law enforcement. In both knife and gun attacks, α increases as the number of students increases from 10,000 to 12,000. This shows that in both attacks, the number of students willing to fight drastically affects their chances of stopping the attacker. Therefore, the best strategy during an attack is to muscle up as many people as possible and stop the attacker. However, for a gun attack, the effectiveness of this strategy significantly decreases after the first 30 seconds.

Table 3. α: number of times that the students were able to stop the attacker.

Knife 12,000	**Knife 10,000**	**Gun 12,000**	**Gun 10,000**
33 out of 100	22 out of 100	32 out of 100	20 out of 100

While experiments show that α for both knife and gun attacks are almost identical at the same population level, this result seems to contradict the common perception that a gun is much more dangerous and harder to stop than a knife. However, re-examination of Table 1 shows that a gun is programmed to have a constant accuracy of 48%, even in melee range; whereas by comparison, a knife has 50% more accuracy than a gun in the same range. Therefore, if a student successfully rushes the gunman and closes the gap between them, the gun becomes less effective than a knife and the student can survive longer and have more time to subdue the attacker.

5.2 Limitations & Future Work

This model has limitations since complete real world data is not available. Therefore, results presented here should be used for comparing the degrees of similarities and differences in the outcomes between a knife attack and a gun attack. In the future, it can be improved in the following ways to make it more accurate in simulating the agent interactions during an attack:

1. Use an uneven distribution of students by putting more in buildings and less on roads and model students attending class and leaving class.

2. Add in another parameter that increases an agent's possibility of joining the fight the more people it sees fighting the attacker. For instance, if an agent sees its friends fighting the attacker, he will join in too, instead of fleeing the scene.
3. Currently, students fighting attackers only uses probabilities to calculate who dies. However, in a real fight there are many more factors to consider, such as an individual's physique, training, teamwork, availability of possible weapons (such as a chair in the classroom), ballistics, etc
4. Program the attacker to avoid pursuing law enforcement instead of just moving randomly. This can potentially give the attacker more time to do damage and prolong the simulation.

6 CONCLUSION

In China, mass stabbing incidents prove to be an enormous challenge for school security and safety of the students. Although much research has been done on school mass shooting incidents, study on stabbing incident is extremely limited. The agent-based model in this paper utilizes a GIS map and investigates the key similarities and differences between a knife attack and a gun attack on the same campus. Although a gun attack can cause double the casualties as a knife attack, the chances of students stopping a gun attack and the chances of them stopping a knife attack are surprisingly similar. A knife attacker can be overwhelmed at any time during its attack. However, in a shooting, the first 30 seconds are the golden window for a student to take down an attacker; after that, students should wait for law enforcement.

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AUTHOR BIOGRAPHIES

JING YANG (SUNNY) XI is a masters student at the Tsinghua-Berkeley Shenzhen Institute (TBSI), Tsinghua University, China. He holds a B.S. in Mechanical Engineering from the University of California, Berkeley. His research interests include emergency evacuation, disaster management and security research. His e-mail address is sunnyx@berkeley.edu.

WAI KIN (VICTOR) CHAN is Professor of the Tsinghua-Berkeley Shenzhen Institute (TBSI), Tsinghua University, China. He holds a Ph.D. in Industrial Engineering and Operations Research from the University of California, Berkeley. His research interests include discrete-event simulation, agent-based simulation, and their applications in social networks, service systems, transportation, energy markets, and manufacturing. His e-mail address is chanw@sz.tsinghua.edu.cn.