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CROWD EVACUATION DURING SLASHING TERRORIST ATTACK: A MULTI-AGENT SIMULATION APPROACH

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ABSTRACT

Attacks by terrorist using sharp objects such as knives and axes occurred frequently. The evolution of the slashing event involves many factors. A system exploration is needed to reveal the mechanism, find key factors, and choose effective response. We built agent-based model of terrorist and civilian and explored the process of evacuation during slashing attack. We formalized the attack process of terrorist using a finite state machine, and analyzed the characteristics of sharp weapons. We proposed a civilian behavior model based on the perception-decision-behavior framework. In emergency state, civilian takes action based on the current situation and his/her individual characteristics. Based on the multi-agent model, we developed a simulation software. Evacuation in slashing event is simulated to study the relationship between civilian's characteristics and the event consequence. The results show that the civilian's observation range and risk sensitivity have significant impact on the number of casualties.

1 INTRODUCTION

Violent attacks by terrorists against civilians have occurred many times, causing serious casualties and social panic. Many countries have strict control over dangerous objects, such as guns, explosives and radioactive sources. However, anyone can easily access sharp objects such as knives and axes. According to incomplete statistics of GTD, from 2000 to 2015, there were 1,249 terrorist attacks with knives and sharp objects worldwide, resulting in 3,071 civilian deaths (National Consortium for the Study of Terrorism and Responses to Terrorism 2018). In recent years, there have been many slashing attacks incidents, causing a large number of casualties. For example, on March 1, 2014, Kunming Railway Station, China, a group of terrorists hacked the masses with knives, 31 were killed and 141 were injured (China.com 2014). On November 29, 2019, a terrorist carried out stab attack at London Bridge, two were killed and three others were injured (BBCNews 2019).

Terrorists may use sharp objects to attack civilians in public place, and this kind of slashing incidents are difficult to avoid completely. Compared with other types of attack events such as bombing and mass shooting, there are three distinctive features of slashing attack:

- Slashing attack event may last much more time. For example, the attack event in Kunming, China, last around 12 minutes till the terrorists were subdued.
- In the process of slashing, there are complex interactions between terrorists, civilians, security guards, etc. The number of terrorists, weapon type, tactic of attack, and the response of civilians are complex and changeable.

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- Slashing event is taking place in a certain space. The development of the event is affected by many spatial factors, such as spatial layout, number and location of exits.

Therefore, slashing attacks are carried out in a certain space, and the terrorists interact with civilians forming complex dynamic. The dynamic of the event is influenced by many factors. It is necessary to understand the characteristics of the slashing attack and reveal the impact of different factors.

2 LITERATURE REVIEW

There are many studies on terrorist attacks. Especially after the 9·11 incident, many researches have conducted from different perspectives. Most studies focus on terrorist attack events which have occurred frequently in recent years, such as suicide bomber (Usmani and Kirk 2009), mass shooting (Hayes and Hayes 2014), biochemical weapon (Song et al. 2013), and poisonous gas (Wan et al. 2014). There are a few studies on slashing with sharp objects. Liu extended the social force model and studied the effects of spatial layout, number of terrorists, and initial distribution on the consequences of this kind of event (Liu 2018). Chen studied the evacuation process, and analyzed the effects of sensitivity factors, attack intensity, and population density (Chen et al. 2018). Wang investigated the crowd dynamic in public space using video (Wang et al. 2019).

So far the research on the behavior of terrorists and civilians in terrorist attacks is not enough. There are only some studies on the behavior of civilians in disasters, such as building fires. Kuligowski surveyed the survivors of the World Trade Center in the 9·11 incident (Kuligowski 2011), and proposed a predicting human behavior model during building fires (Kuligowski 2013). This model is a conceptual framework, and the input factors and mechanisms of each stage are not specifically designed. Reneke proposed an evacuation decision model (EDM), which classifies the individual state in the pre-movement stage into normal, investigation and emergency (Reneke 2013). Based on the EDM model, Lovreglio further considered the influence of demographic characteristics and personal characteristics (Lovreglio et al. 2016). Kinateder summarized the impact factors of risk perceived (RP) in building fires and the relationship between RP and protective actions (Kinateder et al. 2015).

These studies revealed some psychological-behavioral characteristics of civilians, which provides a basis for the study of terrorist attacks. In this paper, we establish an agent-based model to investigate the evacuation of civilians during slashing attack. This paper is organized as follows. Section 1 introduced the slashing attack events. Section 2 reviewed the related studies. Section 3 built a terrorist behavioral model. In Section 4, the behavior model of civilians is established. Section 5 explored the impact of the characteristics of civilians on the consequences of the event. Finally conclusions were given.

3 TERRORIST BEHAVIORAL MODEL

3.1 Attack Process

In public place, terrorists may use sharp objects such as knives, axes, swords, etc., to attack civilians. In this type of attack, the basic actions of terrorists include: choosing a target, approaching the target and carrying out the attack. The attack process can be described by a finite state machine, which has three states: selecting target, approaching target, and executing attack. These states and the transitions among states are shown in Figure 1.

When a terrorist starts to attack, he/she is firstly in the "selecting target" state, to select a civilian as target based on criteria, and then transfer into the "approaching target" state. In the "approaching target" state, he/she moves quickly, try to get close enough to the target. During approaching, he/she maybe abandon the target, and return to the "selecting target" state. There are some reasons for giving up the current target, e.g. the target moving too quickly to get close, or found a more valuable civilian. In the "approaching target" state, once he/she is close enough to the target , he/she will transfer to the "executing attack" state, and start to slash the target. The slashing action may be performed for many times. In the attacking process, if the target counterattack, or the target flee away, the attack may be withdrawn. In each state, it is possible for the terrorist to stop the attack because losing the intention of attack.

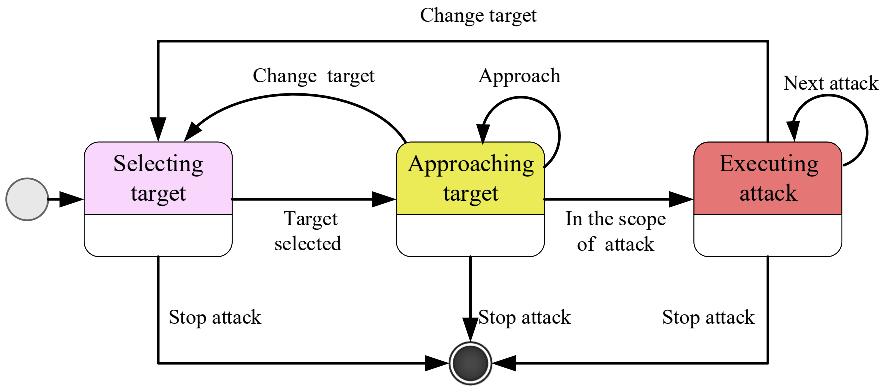


Figure 1: Finite state machine for terrorist attack process.

3.2 Target Selection

It is difficult to determine how a terrorist chooses a target. Roughly, the selection strategy can be divided into two categories. The first is to choose a target based on some criterion, such as social role, age, gender, and so on. The second is to select a target randomly. The common strategies for random selection is to choose one person in dense areas near to the terrorist.

We simplify the random strategy as follows. The 360° range around the terrorist is divided into 8 fan-shaped areas with an angle of 45°. Count the number of people in each sector within a certain distance, select the sector which has the largest number of people as the attack direction, and select the closest civilian in this sector as the target. If there are more than one civilians in the nearest distance, randomly select one.

3.3 Attack Range

When a terrorist uses sharp object to attack, he/she can only cause damage when the weapon could make physical contact with civilian. The effective attack range can be viewed as a sector centered on the terrorist's body. There are three parameters: the maximum attack distance r_{max}, the minimum attack distance r_{min}, and the angle θ, as shown in Figure 2.

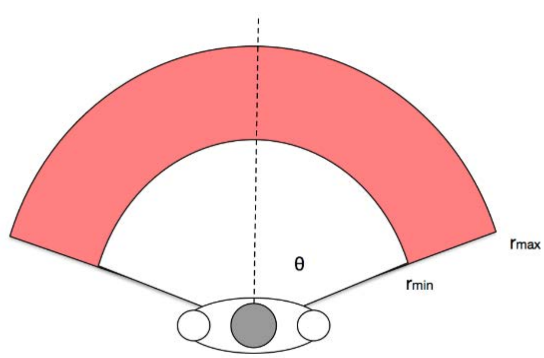


Figure 2: Attack range of a sharp object.

The maximum attack distance r_{max} is approximately equal to the distance from the center of the body to the end of the weapon, which is

$$r_{max} = shoulder\ width/2 + \ upper\ arm\ length + forearm\ length \quad (1)$$
$$+grip\ length + tool\ length - tool\ holder\ length$$

To implement an effective attack, the tool must be accelerated within a certain distance. When the upper arm is fully bent close to the torso and the forearm is attacked, the minimum distance is the shortest attack distance, which is

$$r_{min} = shoulder\ width/2 + \ upper\ arm\ length \quad (2)$$

Generally a terrorist can only attack a target in front of him. According to human physiological data, the human eye has a field of view of 124°. It can be considered that terrorist may attack civilians within the range of $\theta = \pm 62°$.

A terrorist using a sharp object cannot continuously launch attack. The time interval required between two adjacent attack is subject to a random distribution, and the distribution parameters are determined by the attack mode, and the average time scale is between several seconds and several tens of seconds.

4 CIVILIAN BEHAVIORAL MODEL

4.1 The Behavioral Framework

Civilians in public space are usually in normal state. During attack event, their psychology and behavior have a dynamic evolution process. At the beginning of the attack, a civilian can't immediately be aware of it. Only after a period of time, the individual perceives some cues and draws attention to the event. Noticed the abnormal situation, civilian need to further collect relevant information. When the individual believes that his safety is threatened, he enters the state of emergency and takes actions.

In the response stage, civilians and terrorists play a dynamic game. In this stage, both of them continue to collect information, assess the situation, make decision, and execute activities. The most important factor affecting civilian is the level of risk perceived (RP), which has a fundamental impact on mental state, decision-making pattern, and behavioral choice. Based on the EDM framework (Lovreglio et al. 2016), combined with the characteristics of terrorist attack, the response process of civilian is abstracted into an RP-centric framework, including perceived cues, perceived risk, psychological state, decision making, and taking action, as shown in Figure 3.

In the stage of perceived cues, civilian collects information, including the number and location of terrorists, the behavior of surrounding people, and space-related information. Individual synthesizes information to form situation awareness, which determines the risk perceived. The risk perceived is normalized as a [0, 1] continuous variable with two thresholds R_I, R_E. According to the level of RP, the individual's psychological state is divided into normal ($0 \leq RP < R_I$), investigating ($R_I \leq RP < R_E$), and emergency ($R_E \leq RP \leq 1$). In normal state, the individual believes that there is no risk. In investigating state, the individual often slows down current activity and further collects clues. In emergency state, individual may adopt different decision-making mode (heuristic, experimental, bounded rational) and take action.

The behavior of civilian in a real event is influenced by personal characteristics, group characteristics, and environmental characteristics. Individual's physiology, psychology, experience, social role, etc. are different, and the choice of behavior will be different. The demographic characteristics, occupational background, and health level of the group will also have impact. The type of public space, spatial layout, equipment and facilities, and surrounding space all have a certain impact on individual behavior.

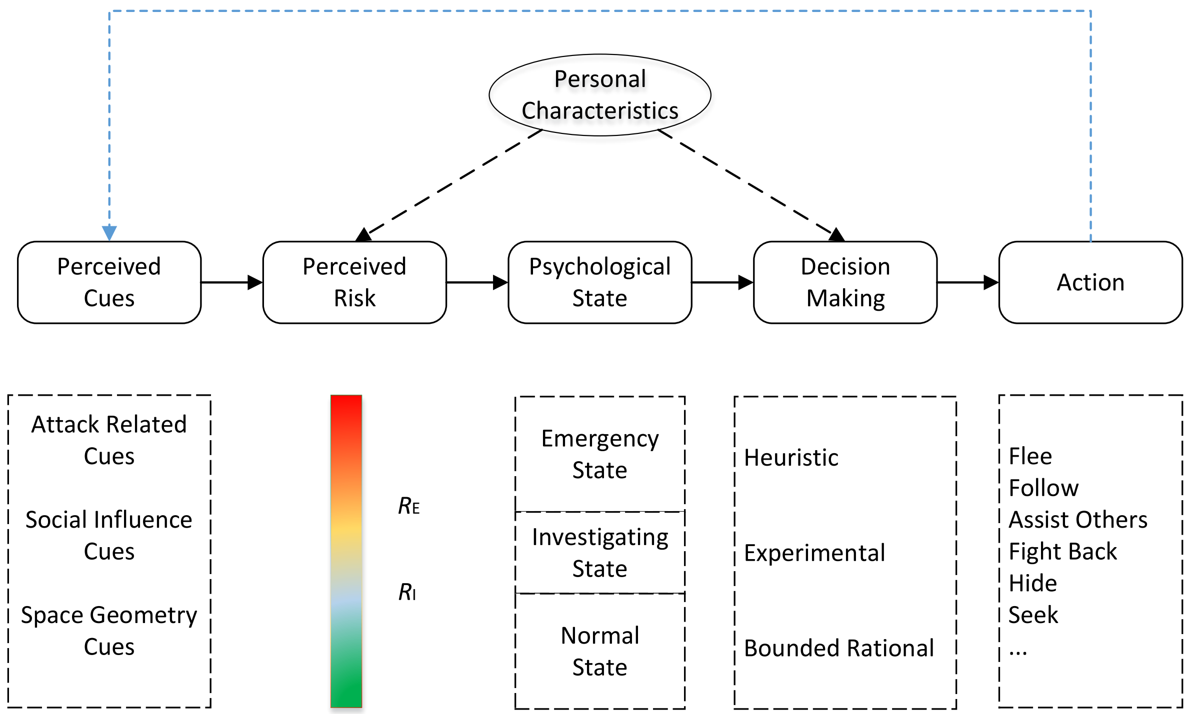


Figure 3: The psychological behavior framework of civilians in attack event.

4.2 Risk Perceived

During attack event, civilian collects relevant cues and then generates perceived risk. There are many cues in the terrorist attack event, which are roughly divided into direct cues and indirect cues. Direct cues are mainly visual or auditory information generated by terrorist. These cues are strongly irritating and have a greater impact on the perceived risk of civilian. In addition, civilian will infer the state of the event based on some anomalies, which will affect the individual's perceived risk. The indirect cues are mainly caused by the public reaction caused by the attack, such as rushing out, shouting, hiding.

Among these many cues, the most important direct cue is the state of the terrorist. The most important indirect cue is the state of the surrounding civilians. The individual's perceived risk level is mainly determined by these two cues.

4.2.1 Direct Cues

In attack event, terrorists are the source of danger and cause psychological pressure on civilians. Perceived risk is related to the distance from terrorists, the level of violence of terrorists, and the number of terrorists.

For the impact of this direct cues, we assume:

- The smaller the distance between the individual and a terrorist, the greater the perceived risk.
- The greater the terrorist’s ability to attack, the greater the perceived risk.
- The psychological pressure of many terrorists on a civilian has a cumulative effect.

Set that there are n terrorists in the public space. The distance between the civilian and the terrorist i is d_i, and the attack intensity of the terrorist i is A_i. The perceived risk is:

$$R_{direct} = \frac{\sum_{i=1}^{n} \delta_i A_i e^{-d_i}}{\sum_{i=1}^{n} \delta_i A_i} \tag{3}$$

The reduction factor δ_i indicates that if there is an obstacle between the civilian and the terrorist i, the psychological impact caused by the terrorist becomes smaller.

4.2.2 Indirect Cues

In addition to direct cues, a civilian also observes the behavior of the surrounding civilians and speculate on their psychological state. If someone around him showed abnormal behavior (such as rushing, shouting), it can be inferred that he is in a state of emergency, causing psychological stress on the individual.

We assume that the greater the number of civilians in emergency state around the individual, the greater the psychological stress on the individual.

Assume the individual's observation range is a circle of radius r. There are N civilians in the observation area. If the number of people in emergency is N_E, the risk level of indirect leads is:

$$R_{indirect} = \frac{N_E}{N} \tag{4}$$

4.2.3 The Risk Perceived

RP is the accumulation of psychological effects caused by direct and indirect cues. So we get

$$RP = \alpha R_{direct} + (1-\alpha) R_{indirect} \tag{5}$$

where $0 \le \alpha \le 1$ indicates the proportion of direct cues affecting perceived risk level. The α indicates the extent to which an individual is affected by surrounding individuals, and the smaller the α, the more likely it is to follow the around crowd.

4.3 Exit Choice

In the terrorist attack event, the most common behavior of civilian is to flee quickly. When escaping, civilian must first choose an exit. Suppose civilians know the location of the terrorists and are familiar with all the exits. The spatial relationship is shown in Figure 4. The location of the civilian is noted as $O(x, y)$, the location of the terrorist j is noted as $T_j(x_{T_j}, y_{T_j})$, and the center of the exit i is noted as $E_i(x_i, y_i)$.

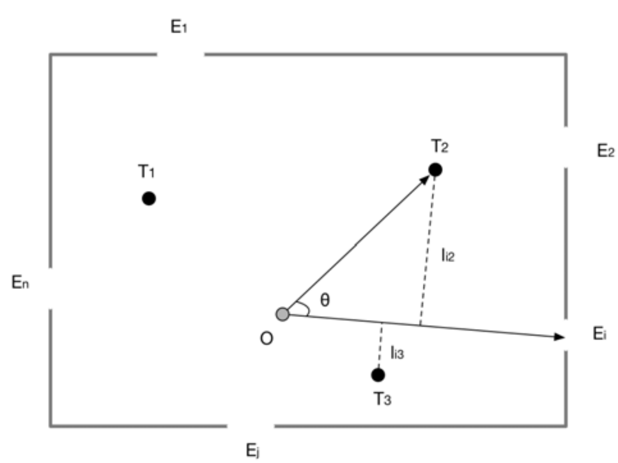


Figure 4: The spatial relationship in exit selection.

Logit model is used to characterize the exit selection decision. The utility of an exit to the civilian is related to two factors: the length of the escape route and the threat of terrorists to the escape route. Obviously, the closer to the exit, the higher its utility. In addition, due to the presence of terrorists, a civilian try to avoid being close to terrorists when moving to the exit. The possibility of proximity depends on the geometric relationship between terrorists and the escape route.

It is easy to calculate the shortest line length D_i from the current position of the civilian to the exit *i*, and normalize the D_i to obtain:

$$d_i = \frac{D_i}{max_i\{Di\}} \tag{6}$$

For an exit, if a terrorist is in the front of the escape route, the threat is greater, and if a terrorist is behind the route, the threat is less. For the exit E_i , and the terrorist T_j, the angle θ between $\overrightarrow{OT_i}$ and $\overrightarrow{OE_j}$ can be calculated. If -π/2 ⩽ θ ⩽ π/2, there is a danger of being intercepted, otherwise the threat is considered to be zero.

For exit i, traverse all N_T terrorists that can generate threats, and use the shortest distance l_{ij} of the terrorist to the escape route to indicate its threat. Accumulate the threat effects of multiple terrorists and normalize them. The danger level of exit *i* is:

$$Danger_i = \frac{\sum_j e\,xp\left(-l_{ij}\right)}{N_T} \tag{7}$$

The determined part of the utility of exit *i* is

$$V_i = (1 - d_i)(1 - Danger_i) \tag{8}$$

The probability that an individual chooses to exit *i* is:

$$P_i = \frac{\exp(\beta V_i)}{\sum_{i=1}^{n} e\,xp(\beta V_i)} \tag{9}$$

5 SIMULATIONS

5.1 Simulation Test

We developed a multi-agent simulation software to investigate crowd evacuation during slashing attacks. We choose a typical open public square, which is a rectangle of 75×40 m, with one entrance (exit) on each side, labeled as exit1,exit2,exit3 and exit4. The width of each entrance is 15 m, and some buildings are distributed inside the square. In starting stage, some people entered the space and moving with his route. Then an attack event happen.

We have simulated the attack event for many times. Here we select one simulation run to demonstrate. We took many snapshots during the process, which are shown in Figure 5. A civilian is represented by a small circle, which has three different colors, indicating different mental states: green is normal, yellow is investigating, and red is emergency. The civilian targeted by a terrorist is surrounded with a blue ring. The terrorist is represented by a larger orange circle, the attack range is shown with a red ring, and the observation range is shown with a dotted ring.

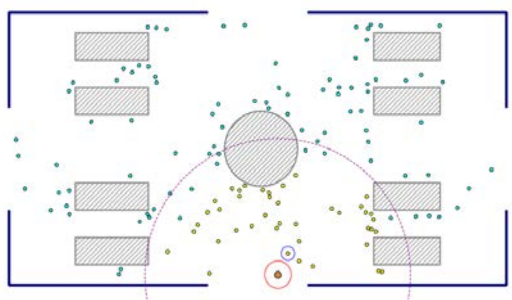
At t_0 , a terrorist enters the square from exit4. He chooses the nearest civilian within his observation range to attack. After a period of time, civilians perceive the attack and enter the response process. Starting from t_0, we simulate the attack event for 10 minutes.

At t=5s, the terrorist selected a civilian as target and start to chase him. The surrounding civilians perceived event-related cues, but the perceived risk level is lower than the emergency response level and enters the investigating state (yellow). The civilians far from the terrorist do not perceive enough dangerous information and are still in normal state (green).

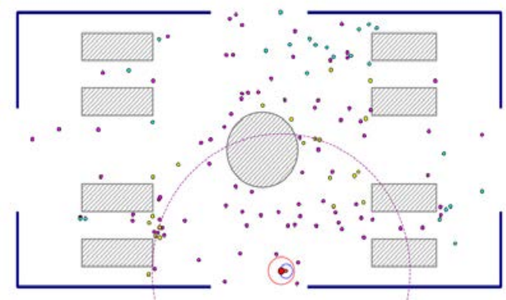
At t=15s, the targeted civilian is within the range of attack, and the terrorist is attacking him. The nearby civilians detected strong danger signals, most of them entered the state of emergency (red) and quickly fled to the exit away from the terrorist. But some of the further civilians are still in watching state (yellow), and a few civilians are not aware of dangerous and still in normal state (green).

At t=25s, the terrorist killed the target, then chose another civilian as new target, and began to chase him. Most civilians are in the state of emergency and fled to the exit.

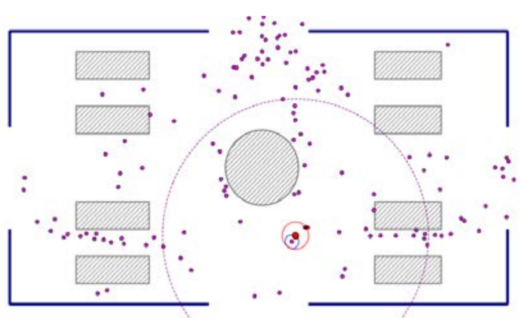
At t=35s, the terrorist are chasing the new target, and most of the surrounding civilians move away from the terrorist and fled to chosen exit quickly.



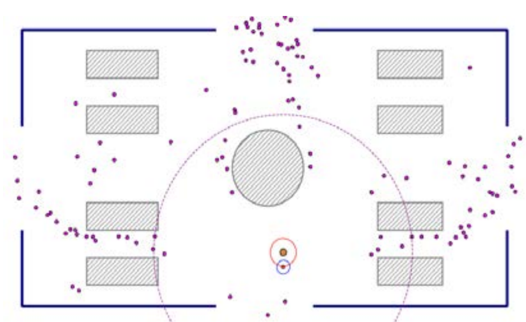
(a) Snapshot at 5s



(b) Snapshot at 15s



(c) Snapshot at 25s



(d) Snapshot at 35s

Figure 5: Snapshots of terrorist attack process.

To validate the model, we collected 10 surveillance videos of attacking events from the Internet. We compared the patterns in real events and the patterns in the simulation. In those videos, crowd show some patterns which are similar to the patterns in simulation. For example, when attack starts, those people near the terrorist enter wait-and-see state. As the terrorist approach and the people nearby enter into emergency, civilian gradually turn into the state of emergency and then flee away from the terrorist. When the distance to the terrorist become large again, they reenter the wait-and-see state.

5.2 Civilian Characteristics and Casualties

The consequence of attack event is affected by many factors, including the spatial layout, the number of terrorists, the manner of terrorist attacks, the composition and attributes of civilians. Attacks may have many effects, but the most important is the number of casualties. In this paper we explored the relationship between civilian characteristics and the number of casualties.

With the typical square with four exits, now we set the width of each exit to 2 m. There are 200 civilians distributed in the square. At t=0s, a terrorist entered the square from exit4 and start to attack. Simulate the attack event for 10 minutes.

5.2.1 Observation Range

There are always some objects in the space which may obscure the line of sight, and civilians have different sensitivities to their surroundings. It can be assumed that the observation range of civilian is limited. Assuming that the observation range is a circular, and different radii represent the individual's vigilance level. Let the observation radius of civilian varies from 5 m to 20 m, with a step of 2.5 m. We repeated the simulation for each observation radius 20 times and collected the number of casualties. The mean and standard deviation of the number of casualties in different observation range are shown in Figure 6.

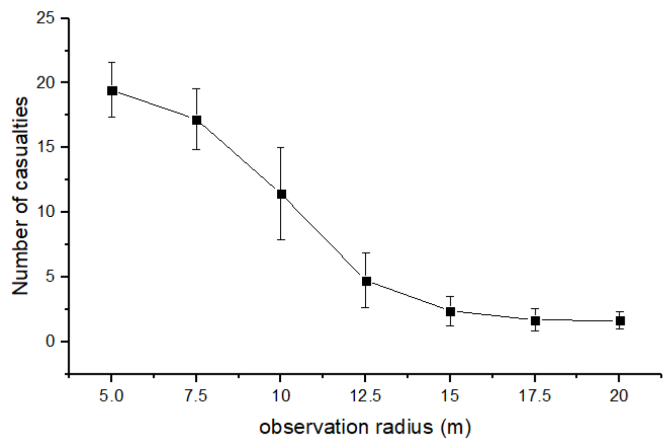


Figure 6: Observation radius and the number of casualties.

The result shows that the scope of observation has a significant impact on the consequence of event. The relationship between the observation radius and the number of casualties is a S-shaped curve. As the observation radius increases, the number of casualties decreases. In the middle range of the radius, the casualty deceases rapidly while the radius increases. The reason for this is that a larger observation radius helps the civilian to early perceive attack, so may take action early. He can avoid the danger of being close to the terrorist, then reduce the possibility of being attacked, and reduce the number of casualties.

5.2.2 Risk Sensitivity

The civilian has three mental states and there are two risk thresholds, R_I and R_E. The different thresholds represent the sensitivity to risk. Set the layout of the square space as above and the observation radius is set to 15 m. Now we set different risk thresholds, R_I takes 0.2, 0.4, 0.6, 0.8, and R_E takes 0.3, 0.5, 0.7, 0.9. For 10 combinations of $R_I < R_E$, simulation was repeated 20 times to collect the number of casualties. The mean of number of casualties in different configurations are shown Figure 7.

It shows that given R_I, the number of casualties increases rapidly while R_E increases. Given R_E, the number of casualties does not change significantly as R_I increases. It implies that R_E is a key factor affecting the casualties. So, when attack occurs, the individual should be in the state of emergency as soon as being aware of the danger, helping to significantly reduce the casualties. However, entering the investigating state at low risk has no significant effect on the casualties.

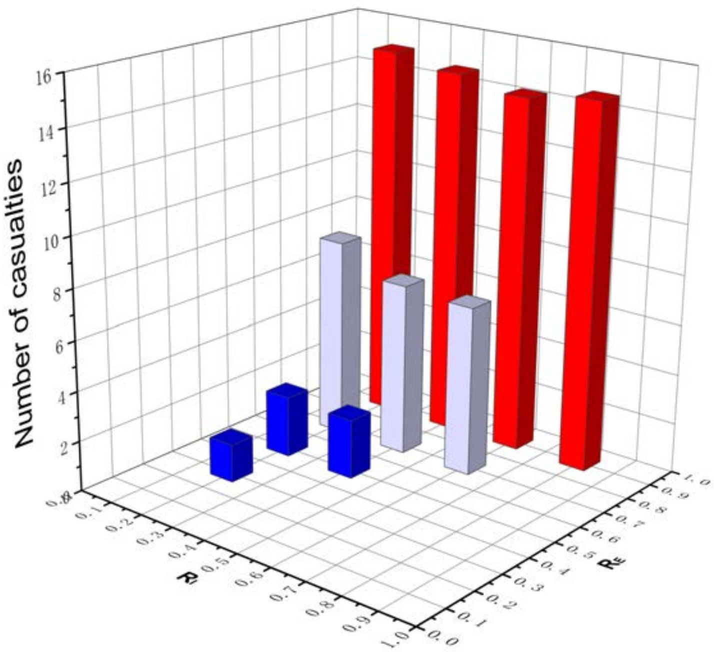


Figure 7: Risk threshold R_I, R_E and the number of casualties.

5.2.3 Emergency Speed

Pedestrians will speed up when they enter the state of emergency. Walking speed in emergency state is affected by many physical and psychological factors. Set the civilian observation radius to 15 m, the risk threshold R_I=0.2, and R_E=0.5. Define the emergency factor *ef* as the ratio of the emergency speed to the normal speed. For *ef* values 1.0~3.0, step 0.5, make 20 simulation replications for each *ef* value, the mean and standard deviation of casualties are shown in Figure 8.

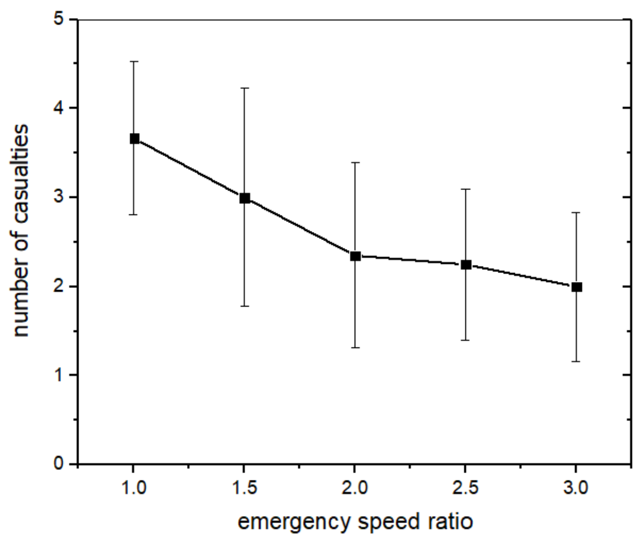


Figure 8: The relationship between the emergency speed and the number of casualties.

As the emergency speed increases, the number of casualties decreases. However, compared with the risk sensitivity and the observation radius, the influence of the speed is not very high. Therefore, increasing the observation radius and lowering the emergency risk threshold have a significant effect on reducing casualties.

6 CONCLUSIONS

Terrorists use knives or axes to chop down crowd in public space may cause heavy casualties and have serious impact on society. It is difficult to prevent such attack event completely. In the process of slashing, terrorists and civilians are playing a dynamic game, and the system evolution is complex. We analyzed the slashing attack, constructed the behavior model of terrorists and civilians with the agent-based approach, and developed a simulation software, which can be used in counter-terrorism research. We explored the relationship between the characteristics of civilians and the consequence of attack event. The results show that observation range and risk sensitivity have significant impact on the number of casualties.

Preventing terrorist attacks in public space is a very complicated problem. This paper only analyzed the simplified slashing event at the tactical level, built behavior model and simulate the process of fleeing from attackers. However the real situation is very complicated. For example, civilians may seek companions, hide, follow blindly and even fight against terrorists. The lack of data on terrorists also makes it difficult to describe their behavior. We should further study and combine with survey, experiment, and big data analysis to build a more realistic model and better support counter-terrorism.

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REFERENCES

BBCNews. 2019. London Bridge attacker convicted of terror offence. https://www.bbc.com/news/uk-50610215, accessed 10th July.

Chen, C., Y. Tong, C. Shi, and W. Qin. 2018. "An Extended Model for Describing Pedestrian Evacuation under the Threat of Artificial Attack". *Physics Letters A* 382(35):2445-2454.

China.com. 2014. Violent terrorist attacks in Kunming in March 1, 2014. https://news.china.com/history/today/0301/index.html, accessed 10th July.

Hayes, R. and R. Hayes. 2014. "Agent-based Simulation of Mass Shootings: Determining How to Limit the Scale of a Tragedy". *Journal of Artificial Societies and Social Simulation* 17(2):5.

Kinateder, M. T., E. D. Kuligowski, P. A. Reneke, and R. D. Peacock. 2015. "Risk Perception in Fire Evacuation Behavior Revisited: Definitions, Related Concepts, and Empirical Evidence". *Fire Science Review* 4(1):1.

Kuligowski, E. 2011. *Terror Defeated: Occupant Sensemaking, Decision-Making and Protective Action in the 2001 World Trade Center Disaster*. Ph.D thesis, University of Colorado at Boulde, Boulder.

Kuligowski, E. 2013. "Predicting Human Behavior during Fires". *Fire Technology* 49(1):101-120.

Liu, Q. 2018. "A Social Force Model for the Crowd Evacuation in a Terrorist Attack". *Physica A* 502:315-330.

Lovreglio, R., E. Ronchi, and D. Nilsson. 2016. "An Evacuation Decision Model based on Perceived Risk, Social Influence and Behavioural Uncertainty". *Simulation Modelling Practice and Theory* 66:226-242.

National Consortium for the Study of Terrorism and Responses to Terrorism. 2018. Global Terrorism Database www.start.umd.edu/gtd/, accessed 10th July.

Reneke, P. 2013. "Evacuation Decision Model". Technical Report NIST IR 7914, National Institute of Standards and Technology, https://www.nist.gov/publications/evacuation-decision-model, accessed 10th July.

Song, Y., J. Gong, Y. Li, T. Cui, L. Fang, and W. Cao. 2013. "Crowd Evacuation Simulation for Bioterrorism in Micro-Spatial Environments based on Virtual Geographic Environments". *Safety Science* 53:105-113.

Usmani, Z. and D. Kirk. 2009. "Modeling and Simulation of Explosion Effectiveness as a Function of Blast and Crowd Characteristics". *The Journal of Defense Modeling and Simulation* 6:79-95.

Wan, J., J. Sui, and H. Yu. 2014. "Research on Evacuation in the Subway Station in China based on the Combined Social Force Model". *Physica A* 394:33-46.

Wang, J., S. Ni, S. Shen, and S. Li. 2019. "Empirical Study of Crowd Dynamic in Public Gathering Places during a Terrorist Attack Event". *Physica A* 523:1-9.

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