Impact of Route Choice on Pedestrian Casualties in Car Bomb Terrorist Attacks

Zhenyu Fan1, 2, Junlin Che1, Yiming Zhai1, 2, Ning Ding1, 2*, Yang lu1, 2
1Public Security Behavioural Science Lab, People’s Public Security University of China, Beijing, China
2College of Investigation, People’s Public Security University of China, Beijing, China
dingning@ppsuc.edu.cn

Abstract. Current situation of international violent terrorism is severe. Public places with high density crowd are more likely to be attacked by violent terrorists. Terrorist attacks such as car bombs are one of the very common and harmful types. “10•28” Beijing Golden Water Bridge Attack is a very typical example. Based on the case analysis of the Beijing Golden Water Bridge Attack, this paper established a simulation model of a car bomb terrorist attack on the basis of the social force model of the Anylogic software platform and conducted simulation experiments on the impact of route choice on pedestrian casualties in the car bomb violent terrorist attack. The simulation results show that: there is minimal damage to pedestrians under a specific route. These conclusions are of great practical significance for the placement and arrangement of safety protection facilities for large-scale event venues.

1. Introduction

In recent years, terrorism has become the primary threat to world stability and regional security and a huge obstacle to peaceful development, and it has increasingly attracted the attention of countries all over the world. Similarly, in the scientific community, it has also become a hot topic of research. In order to cope with the increasingly prominent violent and terrorist situation effectively, many scholars have conducted multi-angle research on the crowd psychology, emergency management, and development rules of violent terrorist attacks. The research on terrorist organization networks is shifting from static to dynamic. In the process of research on terrorist attacks, domestic and foreign scholars have adopted methods such as directed weighted networks and game theory to study the survivability or risk coefficient of targets under terrorist attacks, and have achieved fruitful results.[1-2]. Regarding the prediction of terrorist attacks, scholars at home and abroad carried out a lot of research, Petroff V B et al. [3] Hidden Markov Model for Early Warning of Terrorist Attacks.

Smith [4] systematically analyzed the role of simulation technology in analyzing, predicting and preventing terrorist attacks, and pointed out the development direction for the use of simulation technology to analyze terrorist organization networks. Carley et al. [5] summarized the shortcomings of traditional social network methods, combined organizational theory, cognitive science and network science, proposed a dynamic network analysis method, and applied it to the study of the disintegration of terrorist organization networks. Ahmed et al. [6] analyzed the applicability of the theory of complex adaptive systems to the study of terrorist organizations, and pointed out that terrorist organizations and their environment should be studied as a whole. Based on the concept of workflow in organization theory, Tara et al. [7] simulated the operating mechanism of terrorist organization networks, analyzed the weak
links in the process of terrorist organization planning, organization, and launching attacks in different environments, and helped counter-terrorism departments to detect terrorists in a timely manner. The attack provided guidance. Ondrej Dolezal et al. [8] create a model simulating a part of the terrorist attack in the Tokyo subway in 1995. They using sarin gas and implementation with AnyLogic software and finally finding the possibilities of minimizing the losses using what-if scenarios.

The violent terrorist attacks can’t be reproduced in reality. Considering safety factors, modeling and suicide bombing attacks simulation on computer is an efficient method to deal with this problem. Simulation provides a good solution for solving various difficulties in the real world. Most of the time, if you find the correct solution through physical experiments, the cost is often too high and impractical. For example, to simulate a violent terrorist incident in reality, someone must act as a violent terrorist, someone must act as a victim, and there must be venues, props and so on. Such suicide bombing attacks simulation experiments will consume huge manpower and material resources, and are full of danger and uncertainties. Therefore, this paper chooses to use computer to simulate the system, and use Simulation software to build a model similar to the real world in the computer. An abstract method was adopted, the important parts related to the research were retained, and other details were discarded to make the operation of the model easier. In this paper, we comprehensively consider the social power model and the behaviour characteristics of the crowds and terrorists in large public spaces mentioned above. After investigating the case of the Golden Water Bridge Attack, comprehensive modeling was carried out to ensure the objectivity, authenticity and scientific of the simulation.

2. Model

2.1. The underlying logic and Background settings

The simulation model used in this paper is mainly based on the social force model. The social force model was proposed by Helbing in 1995 and has been widely studied in academia. In the social force model, each individual is described as a Newton-like particle driven by a force. The force experienced by the individual can be caused by physical contact or be driven by psychological factors. During the movement, people are attracted by the destination to produce a self-driving effect, and they also constantly adjust their speed during the movement to avoid collisions with others and obstacles. In the event of physical contact with others or obstacles when in contact, physical forces are generated, including elastic force in the normal direction and friction force that may be generated in the tangential direction. Therefore, in the social force model, person $i$ is mainly driven by three types of forces, named self-driving force $F_{Di}$, social force $F_{Si}$, and physical force $F_{Gi}$, as shown in formula (1). Among them, the first two are psychological forces, which describe the impact of psychological effects on people, and the latter is physical force, which describes the elasticity or frictional force formed by physical contact on people.

$$m_i \frac{dy_i}{dt} = F_{Di} + F_{Si} + F_{Gi}.$$  

The modeling platform used in this paper is Anylogic software, and the satellite plan of Golden Water Bridge and surrounding environment is used for modeling. As shown in Fig 1 and 2, this paper builds a model base map based on the Satellite plan of the Golden Water Bridge and its surrounding environment.

![Satellite plan of the Golden Water Bridge](image)
2.2. Simulation rules

This paper uses Anylogic software platform to build a car bomb terrorist attack model, and its underlying logic is social force model. The model is mainly composed of Agent settings, model environment and simulation rules. The background of the model is Beijing Golden Water Bridge. The basic size ratio and surrounding environment are set according to satellite images. Agent settings mainly include cars with bombs and pedestrians. The parameters and attributes of the above agent can be adjusted in the underlying logic settings and parameter settings. The size of the car is fixed, but the driving speed, driving route and bomb explosion range can be adjusted. Pedestrian settings have many states. Pedestrians in normal state and panic state have different states and parameters.

We set up the pedestrian logic in Anylogic software to define how the crowd walks and moves in the model and use a state diagram to define the different states of the pedestrian. For the crowd, "alive" is the pedestrian's "alive" state, "dead" is the pedestrian's "dead" state. We set the rules there are two trigger transitions from "alive" to "dead" state, which means pedestrian deaths can be triggered in two ways -- by a car crash or by a car explosion. As shown in Fig 3.

According to the case study, the terrorists drove their vehicle from the east side of the sidewalk, hit a lot of people along the way, and finally crashed to a stop on the Golden Water Bridge. In this paper, a simple vehicle route diagram is drawn through the process modeling library, and the State Diagram is used to make clear the change of vehicle driving state. "Stay" means the vehicle is in a state of waiting, "Move to" means the vehicle is in a state of advancing, and finally "final state" means the vehicle has hit the Golden Water Bridge and stopped. As shown in Fig 4.
This paper sets the vehicle to drive according to the established route for a certain period of time after the simulation starts. It exploded after hitting the guardrail. Then, in order to simulate the scene of a pedestrian falling down after being hit by a vehicle, we set the vehicle to send a message every 0.1 seconds while the vehicle is driving, and pedestrians within 1 meter of the width of the vehicle will receive the message from the vehicle at this time. Once the message is received, the state of casualties appears immediately, which means that the pedestrian has been hit by a vehicle and injured or killed. When the violent vehicle drove to the Golden Water Bridge, it crashed into the guardrail of the bridge and exploded. The car fragments and shock waves produced by the explosion will cause pedestrian injuries and deaths at a certain distance around. By watching the live surveillance video, it can be known that the range endangered by the gasoline explosion in the vehicle is about two meters. As a result, a specific message is sent when the car explodes through the software, and pedestrians within two meters of the car can receive this specific message and assume the same state as the pedestrian who was injured or killed by the impact.

3. Results and Discussion
To study the impact of terrorist route choice on pedestrian casualties, we should start from two aspects, one is the impact of vehicle collision on pedestrian casualties, the other is the impact of vehicle explosion on pedestrian casualties. We conducted experiments on four different routes.

3.1. Impact of vehicle collision
In order to explore the independent effects of a car crash, we set the range of the car explosion to 0, thus ignoring the impact of the explosion. In this experiment, four routes were selected, and the effect of drawing in the model is shown in Fig5. The final experiment result is shown in Table 1.
Table 1  experimental results of four routes

| Route  | Distance travelled/m | Crowd density | Number of Casualties/person |
|--------|----------------------|---------------|----------------------------|
| Route 1 | 120                  | Small         | 10                         |
| Route 2 | 120                  | Large         | 65                         |
| Route 3 | 60                   | Small         | 6                          |
| Route 4 | 60                   | Large         | 30                         |

Dividing the Routes 1 and 2 into one group, and the Routes 3 and 4 into another group, it can be seen that the greater the crowd density in the area passing by the route, the greater the number of casualties caused. Similarly, by comparing Routes 1 and 3 with Routes 2 and 4 separately, we can see that when the route passes through a crowd of roughly the same density, the distance traveled doubles, and the number of casualties nearly doubles, the relationship between the distance traveled and the number of casualties is approximately proportional. To sum up, the length of the route chosen by the vehicle and the density of the people passing through the area will have an impact on the final number of casualties. Specifically, places with a high density of people are more likely to achieve the results that terrorists seek, and the number of casualties is proportional to the distance the car travels.

3.2. Explosive combustion effects

Similarly, in order to explore the impact of the car explosion on the number of casualties in the crowd, the next Route 3 and Route 4 are used as models to calculate the number of casualties caused by the two routes respectively by gradually increasing the scope of the explosion, subtracting the number of pedestrians killed or injured in a car crash from the result gives only the number killed or injured by an explosion. The results are shown in Fig 6.

![Fig 6](image)

Route 3 ends in a less populated area, and Route 4 ends in a densely populated area. The image above shows that detonating a bomb in a crowd of different densities can have completely different effects. In the case of small blast radius (less than 3 meters), casualties in areas of high and low population density were all within 10 persons, and did not very much. When the blast radius is more than 3 meters, with the increase of the blast radius, the number of casualties in the area with high density increases steeply, and the number of casualties exceeds 60 when the blast radius is 10 meters. In contrast, the range of casualties in low-density areas remained fairly constant, with only 20 casualties at 10 meters. Specifically, as the radius of the car explosion increases, so does the number of casualties. The choice of large population density areas for detonation, casualties with the increase in the size of the blast radius and the increase in the magnitude will be more obvious.
4. Conclusion
Based on the above analysis, we used simulation methods to conduct experiments on the impact of route choice on pedestrian casualties in the car bomb violent terrorist attack. The results of the experiment show that there is minimal damage to pedestrians under a specific route. These conclusions are of great practical significance for the placement and arrangement of safety protection facilities for large-scale event venues. Although this paper aims at the simulation of the terrain features of Golden Water Bridge, in fact, this method has commonality in solving such problems. This paper finally provides a good idea to solve such problems and verifies it.

These conclusions can provide some suggestions for the public security agencies to take effective measures when dealing with violent terrorist attacks. However, there are still some limitations need to be further studied and improved in this paper. Firstly, some data such as the rate of pedestrian generation, the time of ticket queue needed in this paper are obtained through literature review and general theory which lack of field investigation. The future research work must use data obtained through field survey to guarantee the accuracy of research result. And due to the limitation of simulation software module, the model is simplified and some unimportant details are neglected. We can’t simulate these violent and terrorist events completely. The model is still need to be further improved.

References
[1] MAJOR J A. Advanced techniques for modeling terrorism risk [J]. Journal of Risk Finance, 2002, 4(1): 15 – 24.
[2] Shi Xiquan. Game theory [M]. Shanghai: Shanghai University of Finance & Economics Press, 2000.
[3] Petroff V B, Bond J H, Bond D H, et al. Using Hidden Markov Models to Predict Terror Before it Hits (Again) [M]: Springer New York, 2013: 163 – 180.
[4] SMITH R. Counter terrorism simulation:a new breed of rederation[C]// Swenson, Steve. Proceedings of the Spring 2002 Simulation Interoperability Workshop. Orlando Florida: Simulation Interoperability Standards Organization(SISO), 2002.
[5] CARLEY K M, JEFFREY R, NATASHA K. Destabilizing terrorist networks[C] // Jared Freeman. Proceedings of the 8th International Command and Control Research and Technology Symposium. Washington DC: National Defense War College, 2003.
[6] AHMED E, ELGAZZAR A S, HEGAZI A S. On complex adaptive systems and terrorism [J]. Physics Letters A, 2005, 337 (1): 127 - 129.
[7] TARA A L, NISSEN M E. Defining and exploring the terrorism field: toward an intertheoretic, agent-based approach[J]. Technological Forecasting & Social Change, 2007, 74(2): 165 - 192.
[8] Ondrej Dolezal, Hana Tomaskova. An Agent-Based Simulation to Minimize Losses during a Terrorist Attack[J]. Applied Sciences. 2020, 10, 3213.
[9] Ding N, Zhang H, Chen T. Simulation-based optimization of emergency evacuation strategy in ultra-high-rise buildings[J]. Natural hazards, 2017, 89(3): 1167-1184.