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A Systematic Approach to Develop a Computational Framework for Counter-terrorism and Public Safety

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A Systematic Approach to Develop a Computational Framework for Counter-terrorism and Public Safety

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It is increasingly important to devise emergency response plans and protocols for counter-terrorism and public safety as terrorists and violent extremists target the innocent public with maximum impact. When terrorist attacks occur despite our best effort, it is crucial to respond rapidly in an organized manner with well-planned protocols, so that the impact can be mitigated. This paper presents a computational framework (GENIUS) that helps develop, simulate, and verify such optimal emergency response plans and protocols. It also includes the use of virtual environments as a tool to study human behaviours in urban environments and train first emergency responders. Experimental results are presented to validate and verify the GENIUS system.

1.0 Introduction

It is the Canadian Government's priority to protect Canadians from any harm and damage caused by terrorists and violent extremists at home and abroad. In order to ensure the safety and security of its citizens, the Government of Canada took the initiative to counter terrorism. The Canadian government developed a framework to build resilience against terrorism by reinforcing four strategic elements: prevent, detect, deny, and respond.

Despite our best efforts, no place is immune to terrorism. The Air India Flight 182 bombing in 1985 killed 329 people including 268 Canadians, the largest mass destruction in Canadian history. The Oklahoma City bombing in 1995, the September 11 terrorist attacks, and many other international and domestic acts of terrorism have claimed numerous innocent lives in North America. The 2006 Ontario terrorism plot was discovered before it was carried out. The plot revealed a terrorists plan to attack major federal government buildings, assassinate political leaders, and open fire on crowds. In recent years, many terrorist attacks have been targeting innocent people and bystanders. Breivik, a right-wing extremist, opened fire at teenagers at a summer camp in Norway in 2011 killing seventy. During the Boston Marathon in April 2013, two bombs that were set by two Islamic extremists exploded in the midst of marathon spectators, killing three people, and injuring numerous more. An Islamic group attacked the Westgate shopping mall in Nairobi, Kenya in September 2013, killing over sixty civilians.

It is a priority to detect terrorist threats and prevent them from happening. However, when a terrorist attack occurs, it is important to respond rapidly and in an organized manner to save lives, reduce personal injuries, and mitigate the damage of such an attack. This kind of immediate and coordinated response requires careful planning and protocols, with the participation of local law enforcement and emergency management authorities. At the same time, incorporating currently available technologies in these strategic response plans and protocols opens a new way to handle chaotic incidents in an effective and systematic manner.

Counter-terrorism initiatives aim at developing effective and efficient strategies and tools in order to prepare against, prevent, and respond to a wide variety of terrorist threats, including chemical, biological, radiological, nuclear, and explosive (CBRNE) threats. As such, Canadian governments and security agencies have been actively trying to improve their capabilities by funding and supporting innovative science and technology approaches that address national public safety and security needs and provide tools for CBRNE response and preparedness.

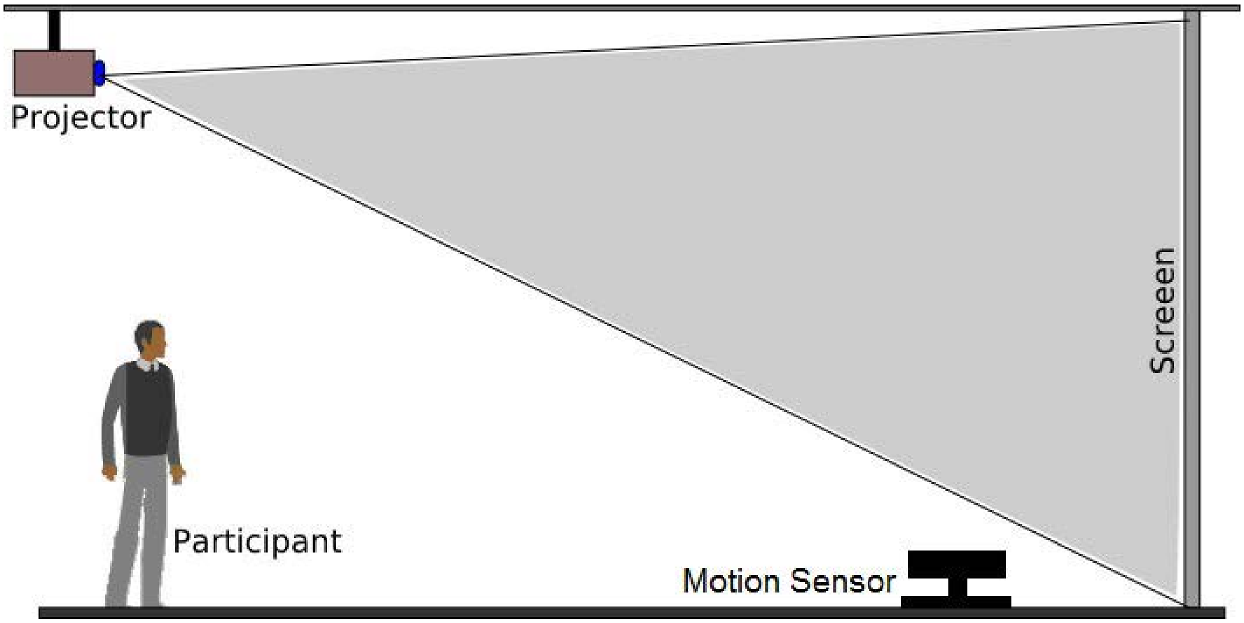
This paper presents an overview of the computational framework that we have developed, the *GENIUS* system (Tsang et al. 2010; Park et al. 2012). *GENIUS* is a framework which provides decisional support, response planning, and risk assessment. The framework helps devise CBRNE response plans and preparedness and it has several components: a) a parametric based human behaviours modeling module, b) a human behaviours simulation module, c) a flexible virtual environment module which we have been using to study human behaviours in a controlled environment, and d) a visualization module that can integrate with both a commercial GIS system and a 3D virtual environment. These modules are all integrated together in order to provide a system that is both modularized and flexible. Because the *GENIUS* system is modularized, it can easily incorporate state-of-the-art technologies available today.

2.0 A Computation Framework for Counter-Terrorism

2.1 Human Behaviour Study using Virtual Environments

In our previous research study, a series of research experiments was conducted to discover patterns of human behaviours in urban environments, in particular, the behaviours that are influenced by fear of crime and perception of crime (Park et al. 2010; Park et al. 2011). These experiments made use of virtual environments to avoid ethical issues for participants. In addition, the use of virtual environments has become affordable, efficient, portable, and reliable. Figure 1 shows a simple experimental setting with a participant.

Figure 1. VE experiment setting



From the analysis and results of these experiments and the literature review of social sciences (LaGrange et al. 1992; Hanyu 1997; Sampson and Raudenbush 1999; Hanyu 2000; Herzog and Flynn-Smith 2001; Weinrath et al. 2007), much knowledge about patterns of human behaviours influenced by fear has been gained. For example, most people are more afraid of social incivilities (prostitution, drug dealing, panhandling, public drunkenness, or homelessness) than physical incivilities (litter, broken windows, abandoned storefronts, unkempt lots, graffiti, or vandalism). The use of virtual environments can be further utilized to study human (crowd) behaviours in the case of emergency.

2.2 GENIUS

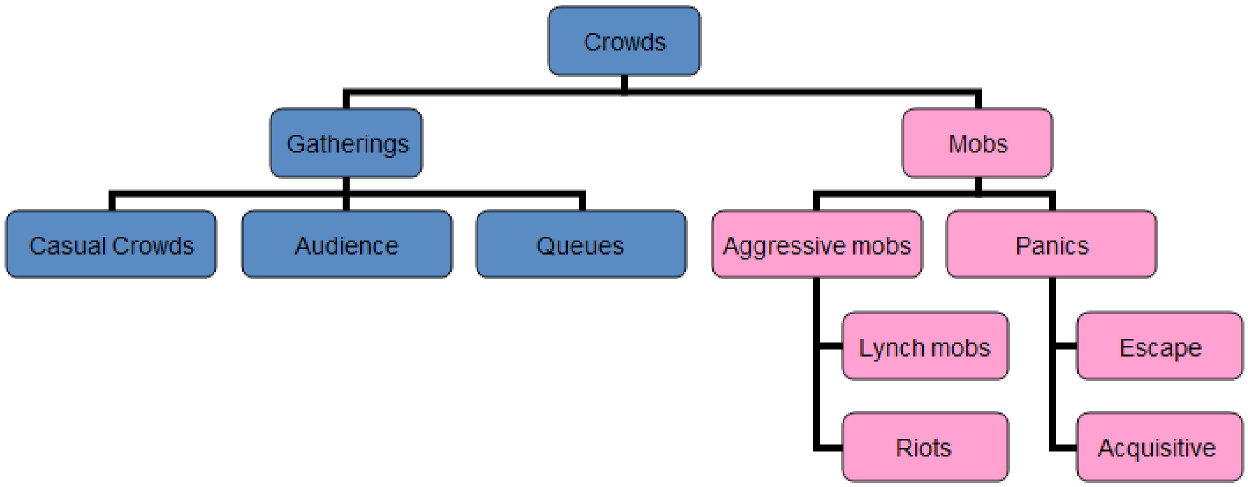
2.2.1 Agent-Based Modeling

Based on the previous study, a computational framework, *GENIUS*, was developed to investigate human behaviors in urban environments. The goal is to capture the complexity and diversity of human behaviors in a robust and systematic way. In the course of developing this framework, we used agent-based modeling (ABM) techniques, and a methodological framework; a tool environment was also developed to address the needs and challenges of modeling complex behaviors. ABM is a class of computational models that simulates the actions and interactions of autonomous agents with each other and the environment (Bonabeau 2002). This approach is based on the idea that a system is composed of decentralized individual agents and that each agent interacts with other agents and the environment according to localized knowledge and rules. The goal of the model is to re-create and predict the appearance of complex phenomena based on the simulation of the simultaneous operations and interactions of multiple agents. The process is one of emergence from the lower (micro) level of systems to a higher (macro) level. As such, a key notion is that simple behavioural rules generate complex behaviours.

The *GENIUS* has an agent behavior engine which was constructed using the s*warm intelligence* (SI) paradigm (Kennedy and Eberhart 1995). The expression *swarm intelligence* was first introduced by Beni and Wang (1989) in the context of cellular robotic systems. Since then, SI has been successfully applied in many areas, including forecasting pedestrian evacuation times (Izquierdo et al. 2009), diagnosis of human tremor (Eberhart and Hu 1999) and a variety of optimization applications. SI is a decentralized and self-organized system where the collective behaviours of agents interacting locally with their environment cause coherent functional global behaviours. Typically these agents are unsophisticated and global patterns emerge from their collective behaviours. SI relies upon countless interactions between individual agents, each of which is following simple rules of thumb. By computing and describing the space-time behaviour of individual pedestrians in a microscopic model, we can observe characteristics of the flow rather than individual pedestrians. This allows us not only to study the behaviours and decisions of individual pedestrians but also their interactions with other pedestrians in the crowd.

Specifically, there are different types of crowd behaviours. Forsyth defined crowds as ``a temporary gathering of individuals who share a common focus of interest” (Forsyth 2010, 503). He classified crowds into many different categories (see Figure 2). In particular, the current *GENIUS* system simulates casual crowds and panic escape models.

FIGURE 2. CLASSIFICATION OF CROWDS



2.2.2 Parametric Modeling

Using a parametric model to model human behaviours is not new in the literature. Wakita, Ozawa, Miyajima, and Takedal (2005) modeled driving behaviour when following another vehicle. Parameters can be varied independently to modify a specific agent's behaviour (e.g. walking speed, memory, decision rules etc.). This authoring paradigm is highly flexible, allowing a wide range of applications. The entire set of parameters can be exposed individually for full low level authoring control or a subset of these parameters with constraints can be presented to a novice user for customization and personalization. In general, agents can be described by the following characteristics (Gilbert 2007):

- perception- the agents can perceive their environment and other agents in their vicinity;
- performance- the agents have a set of behaviors that they can perform and often include motion, communication, and action;
- memory- the agents can record their perceptions of the previous states and actions;
- policy- the agents operate using a set of rules, heuristics, or strategies.

Higher-level constructs can be imposed on the basic parameter scheme by combining low-level parameters to create application specific descriptive elements. In this way we have begun to build up a hierarchical library of behaviours and agent types which all can be combined and changed in any number of ways. In the highest level of the hierarchy of the *GENIUS* system, there are three types of the agent's profile in our model: 1) civilian, 2) police, and 3) terrorist, which all behave differently. Furthermore, the second level of the agent's profile hierarchy can be refined using the following parametric qualities: age (small children, adult, seniors), gender (male and female), and personalities (bold or fearful).

Users can define a number of agents with the same characteristics or create an agent with an individual profile. It was found in the previous study that people had different behavioural characteristics based on their gender and age. Our framework incorporates these findings to create a large number of people with specific behavioural characteristics. Figure 3 shows the visualization of a crowd while the simulation is running.

Figure 3. The 3D visualization of a crowd in the GENUS system

In particular, three distinctive agents in the *GENIUS* system (civilians, police (either first emergency responder or security officer), and terrorists) have different behavioural characteristics. Civilian agents walk to their destinations. However, if there is any kind of terrorist attack (bombing, toxic gas, or shooting), they try to escape from the dangerous zones. Police officer agents can be placed at strategic locations. When terrorist attacks occur, they quickly find and lead civilian agents who are around them to safety or the closest exits if they are in the buildings because the police officer agents have a good knowledge of the environment . Currently, terrorist agents are set to follow a pre-set path and shoot civilians and police officers at first sight (for example, the Westgate Shopping Mall attack).

2.2.3 Emergency Response Plan and Risk Assessment Using GENIUS

Various scenarios of terrorist attacks can be created and simulated in the *GENIUS* system. Environments (buildings and streets) can be created by either mouse clicks on the screen or importing maps. Different attacks such as time bombs and/or toxic gases (biological threats) can be placed at different locations. In particular, toxic gases can be blown by the wind with a specific direction and strength. A different number of people (crowds) with customized parameters can be positioned in different locations. As the simulation runs, it will reflect and show how the crowd behaves when struck with a terrorist attack.

Agents of first emergency responders (RCMP officers and emergency medical responders) can strategically be placed and simulated in the *GENIUS* system. Rescue missions can be carried out within the simulation. By varying the number and locations of these agents, the optical emergency response plans and protocols can be devised, to determine which can rescue the most people in the shortest time.

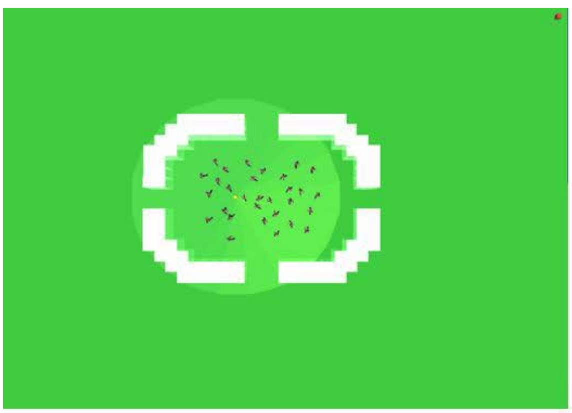
To verify and validate the framework, a set of simulation experiments with different emergency response plans was performed. First, a hypothetical environment and scenario was created in the *GENIUS* system. For the first experiment (Scenario A), thirty citizen agents were placed in a confined building where there were only four exits available. A bomb goes off inside the building and we expected our citizen agents to find evacuation routes.

The explosion of a bomb was simulated with realistic visualization and the behaviours of the people were animated in real-time. Figure 4 shows the setup for the building and the agents. When the bomb went off, people panicked, and tried to escape from the building. However, many of them could not find exits, so that they could not escape. After 100 cycles (simulation time), there were still 10 people inside the building. Figure 4b shows the number of people that escaped over that time. At the time of 100 cycles, only 66.6 percent of the agents escaped.

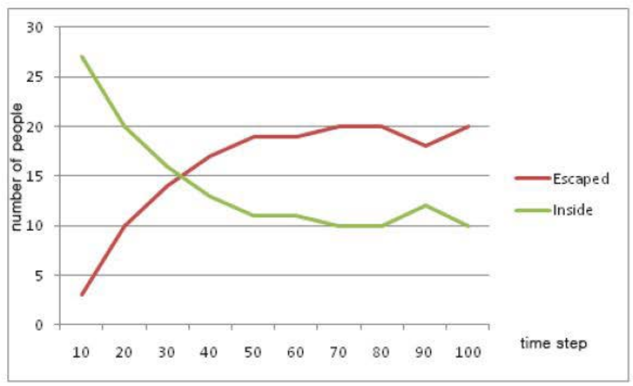
For the second experiment (Scenario B), four emergency responders were added to the same scenario. As shown in Figure 4c, they were placed at each of the exits. After the explosion of the bomb, these responders went into the building and led people out of the building.

Figure 4d shows that 50 cycles (time steps) after the bomb exploded, about 93 percent of the agents escaped. Eventually all citizen agents escaped from the building after about 100 cycles in contrast to the last scenario where only 66.6 percent of the agents escaped.

Figure 4. Initial setup and plots of a typical run



(a)



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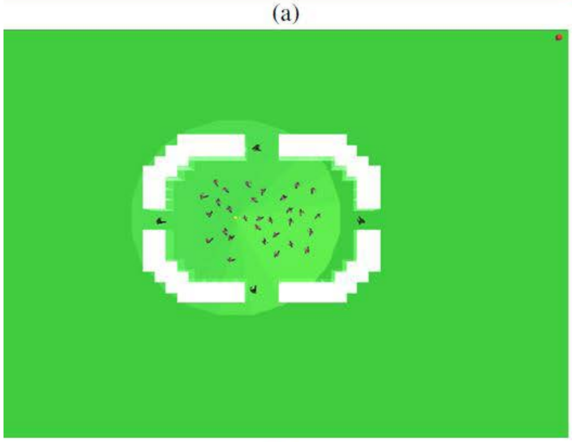
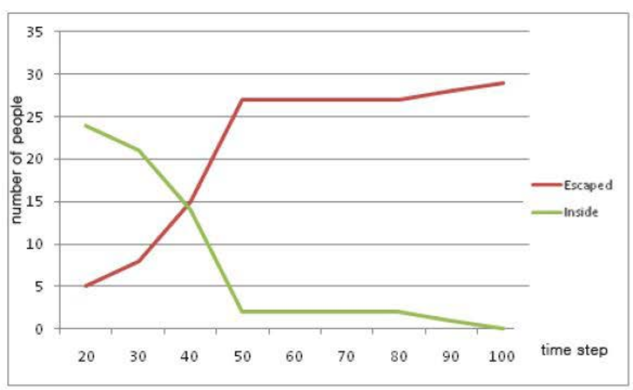


(c)



(d)

The figures which are showing (a) the setup of Scenario A (without emergency responders), (b) the graph which plot the number of escapees over time in Scenario A (without emergency responders), (c) the setup of Scenario B (with emergency responders), (d) the graph which plot the number of escapees over time in Scenario B (with emergency responders).

These two experiments show that the placement of emergency responders makes a big difference in evacuating people from a danger zone. One would expect these emergency responders to have complex knowledge of the environment, and therefore be able to provide more reliable information to the other agents in the crowd. However, these emergency responders operate under very simple rules. In terms of perception, they have better sight distance and peripheral vision than normal agents. They walk faster and in terms of personality, they are bolder than normal agents. The operation rules are also very simple. In the case of emergency, when an emergency responder walks into the hot zone, their duty is to find people and lead them out of the hot zone. They repeat this cycle to try to find more people.

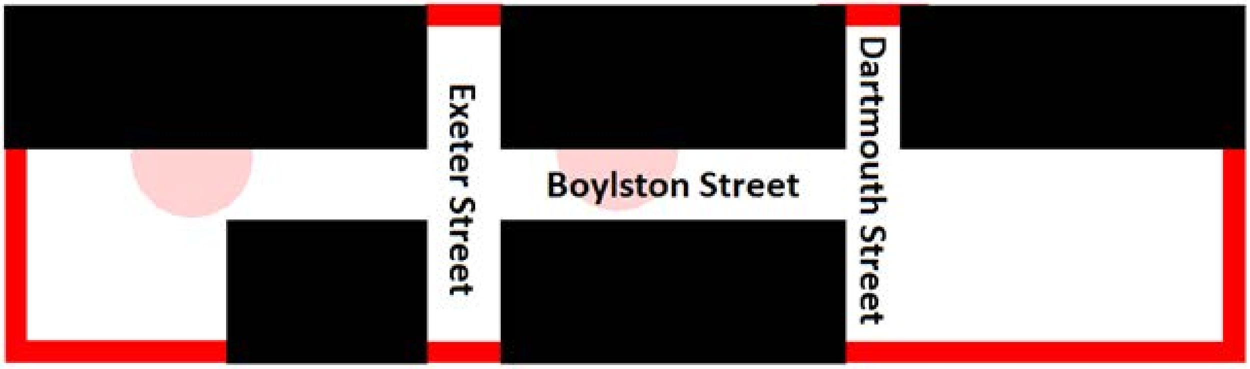
It was observed that with emergency responders in place, they could help civilians reach their destinations faster and more efficiently. This observation both aligned with our intuition and with previous research conducted by Pelechano and Badler (2006).

2.2.4 Simulation of Boston Marathon Bombings

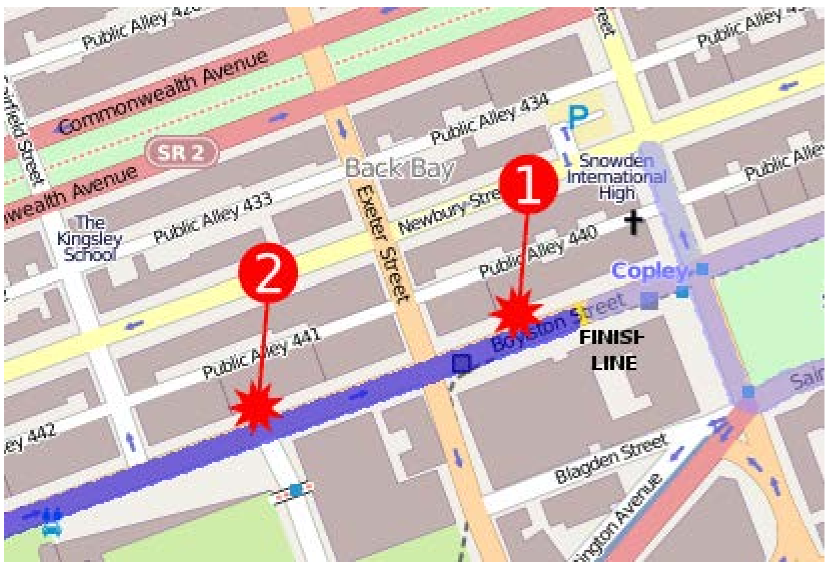
On April 15, 2013, two bombs were ignited among the cheering crowds near the finish line of the 117th Boston Marathon. The local hospitals received many casualties who had severe injuries caused by the explosions. Despite the nature and severity of the injuries, no patient who received hospital care died. Only three people were killed directly by the explosions before reaching a hospital. This very high survival rate was due to the brave and rapid response of first emergency responders and bystanders, rapid transportation of injured patients, and the skilled hospital trauma teams (Walls and Zinner 2013).

Considering the important role of first emergency responders, the Boston Marathon bombings were simulated within a realistic virtual environment using the *GENIUS* system. These simulation experiments are similar to experiments in the previous section. However, the GENIUS simulations were based on the real Boston bombing event. Figure 5a shows the simulation layout based on the physical environment of the real event (Figure 5b).

Figure 5. The layout of the simulation



(a)



(b)

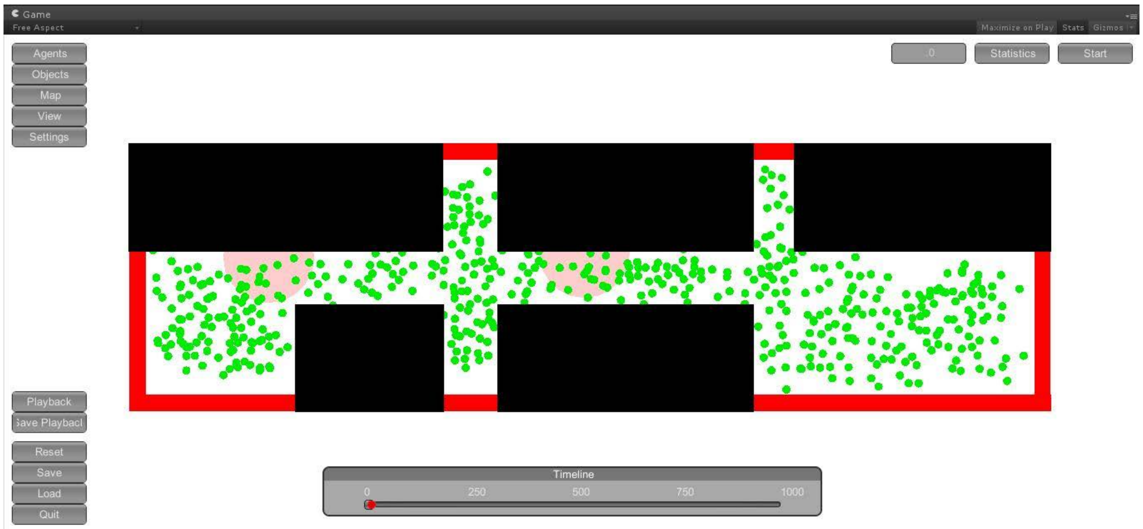
(a) the simulation layout of the Boston Marathon bombings (b) the map showing the two bombing locations.
Source: Data from Wikipedia: http://en.wikipedia.org/wiki/Boston_Marathon_bombings.

The first scenario (Scenario A) consists of only civilians (green dots) without first emergency responders (police officers and emergency medical responders) (see Figure 6a). After the two bombs were ignited, crowds try to escape from the bombed areas. But many of them were panicked and confused and did not know where to go.

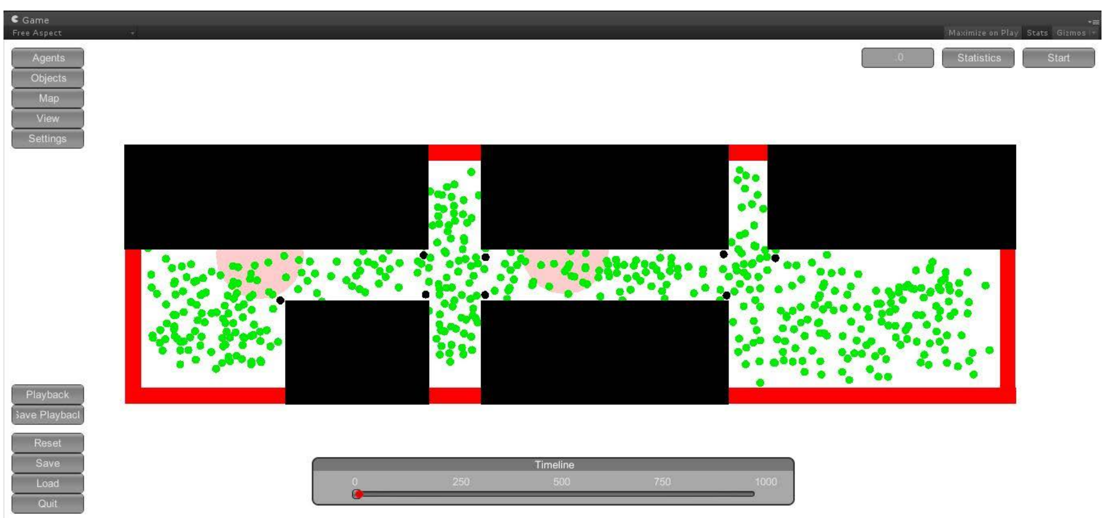
The second scenario (Scenario B) includes both civilians (green dots) and first emergency responders (black dots) (see Figure 6b). These responders were strategically placed near the corners of buildings. They sought to rescue civilians by first leading them out of the dangerous areas. Then the responders came back to the bombed areas, found more civilians, and lead them to escape. They repeated this rescue mission until they found everyone.

Figure 6c shows the comparison between the numbers of escapees over time in Scenario A and Scenario B. It clearly shows that with the help of first emergency responders, civilians can escape quicker than without any help during the critical time right after the bomb explosions.

FIGURE 6. SIMULATIONS OF BOSTON MARATHON BOMBINGS



(a)



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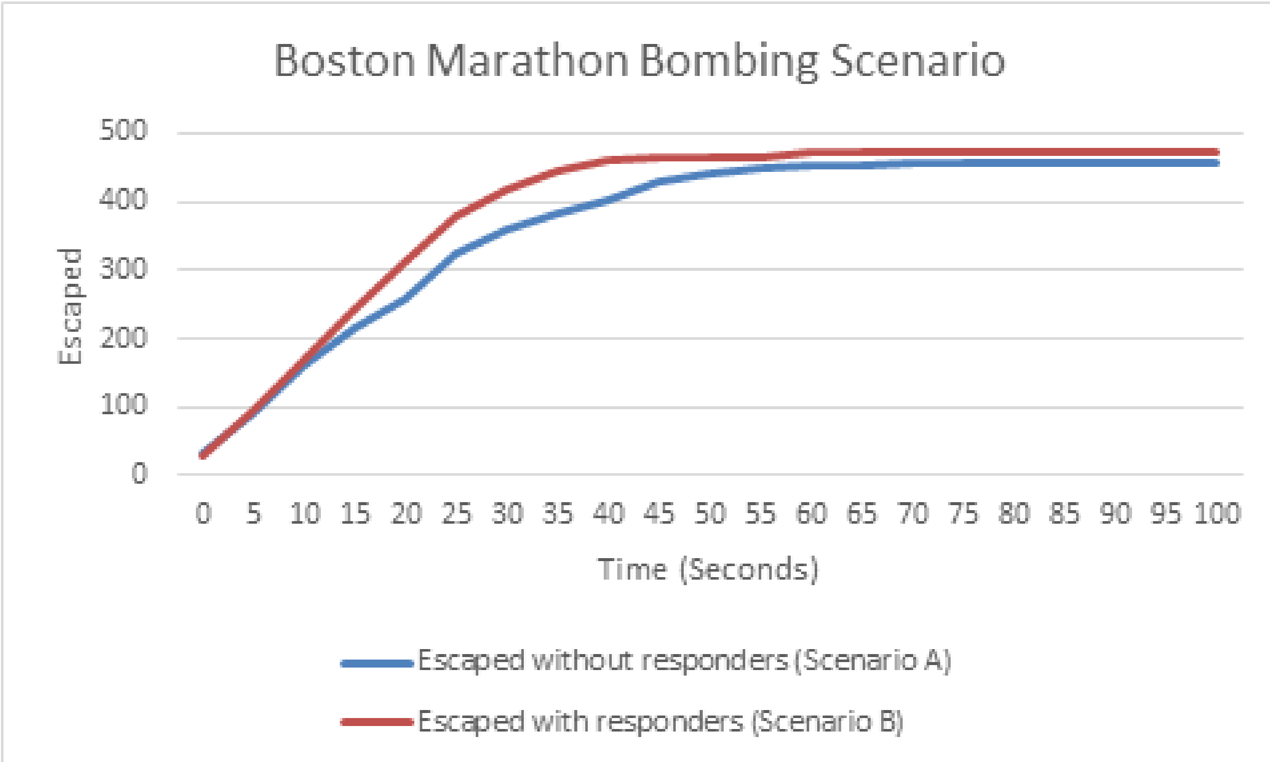


(c)

(a) Scenario A (without first emergency responders), (b) Scenario B (with first emergency responders), (c) graphs of the numbers of escapees over time in Scenario A and Scenario B.

2.2.5 Westgate Shopping Mall Attack

On September 21, 2013, ten to fifteen gunmen attacked the Westgate shopping mall in Nairobi, Kenya. They carried machine guns and AK-47 rifles, and shot and hurled grenades at innocent shoppers and staff (Onuoha 2013). The attack lasted for four days with heavy human casualties killing at least sixty-seven civilians, six security officers, and five suspected terrorists, and injuring over 175 others. The Somali-based Al-Shabaab, an Islamist group that has ties to al-Qaida, claimed responsibility for the attack. They claimed that it was retribution for the deployment of the Kenyan military in Somalia.

The Westgate attack was not totally unexpected since Al-Shabaab repeatedly warned that they would attack Kenya. A big shopping mall at the heart of Nairobi, like the Westgate mall, could be a good target for terrorists to get international attention. If well-trained security officers could have been placed at strategic locations of the shopping mall, they could have made a big difference in rescue efforts during the first few hours of the attack.

Using the *GENIUS* system, the Westgate Shopping Mall attack was simulated with the realistic 3D layout of the mall (Figure 7) and two scenarios.

Figure 7. The layout of the Westgate Shopping Mall (the ground floor)

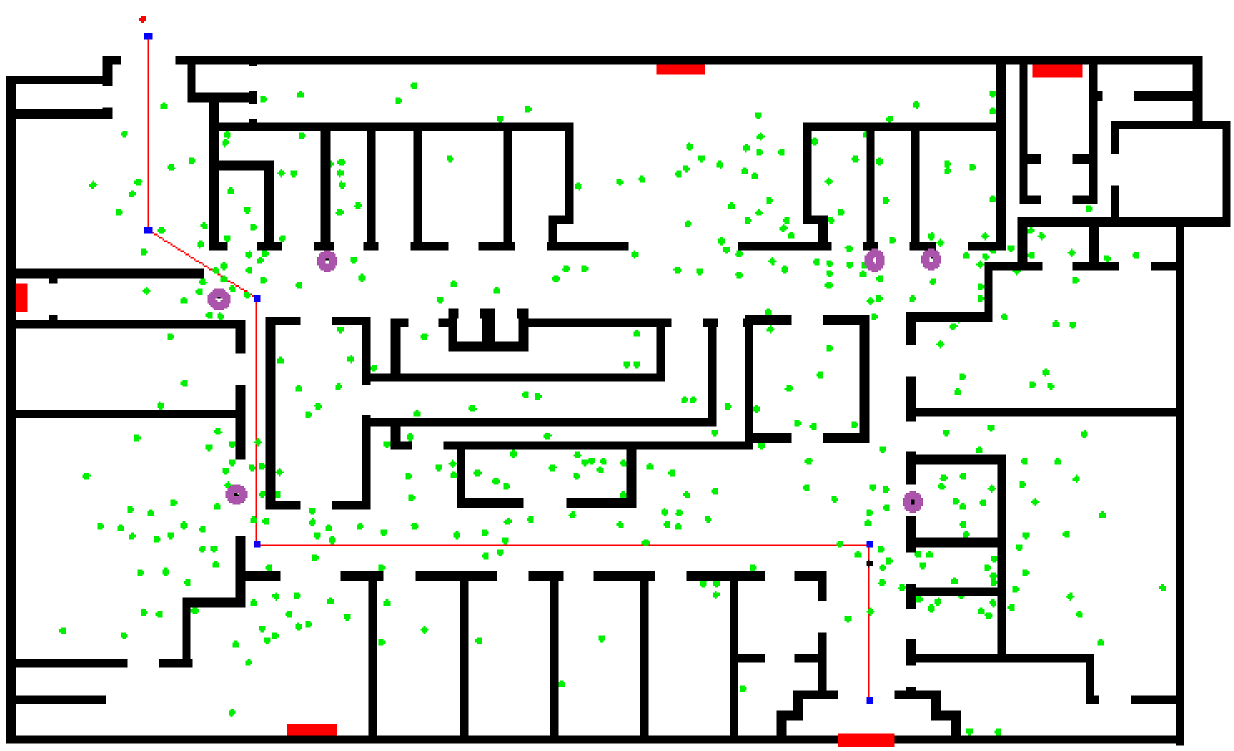
The first scenario (Scenario A) depicts a terrorist attack without any well-trained security officers (Figure 8a). A gunman comes into the shopping mall from the left-top corner, the rear entrance, and begins to shoot people (see Figure 7, the red line shows the path of the gunman). People became panicked and tried to run away from the gunman. However many of them could not find exits because of their panic and fear.

The second scenario (Scenario B) was the same as the first scenario except well-trained security officers are placed at strategic locations of the mall (purple dots) (Figure 8b). These officers quickly act during the initial stage of the attack and lead people to close exits.

Figure 8c shows the comparison between the numbers of escapees over time in Scenario A and Scenario B. It is apparent that many more people can escape with the help of well-trained security than without the well-trained security officers.

FIGURE 8. SIMULATIONS OF WESTGATE SHOPPING MALL ATTACK

(a)



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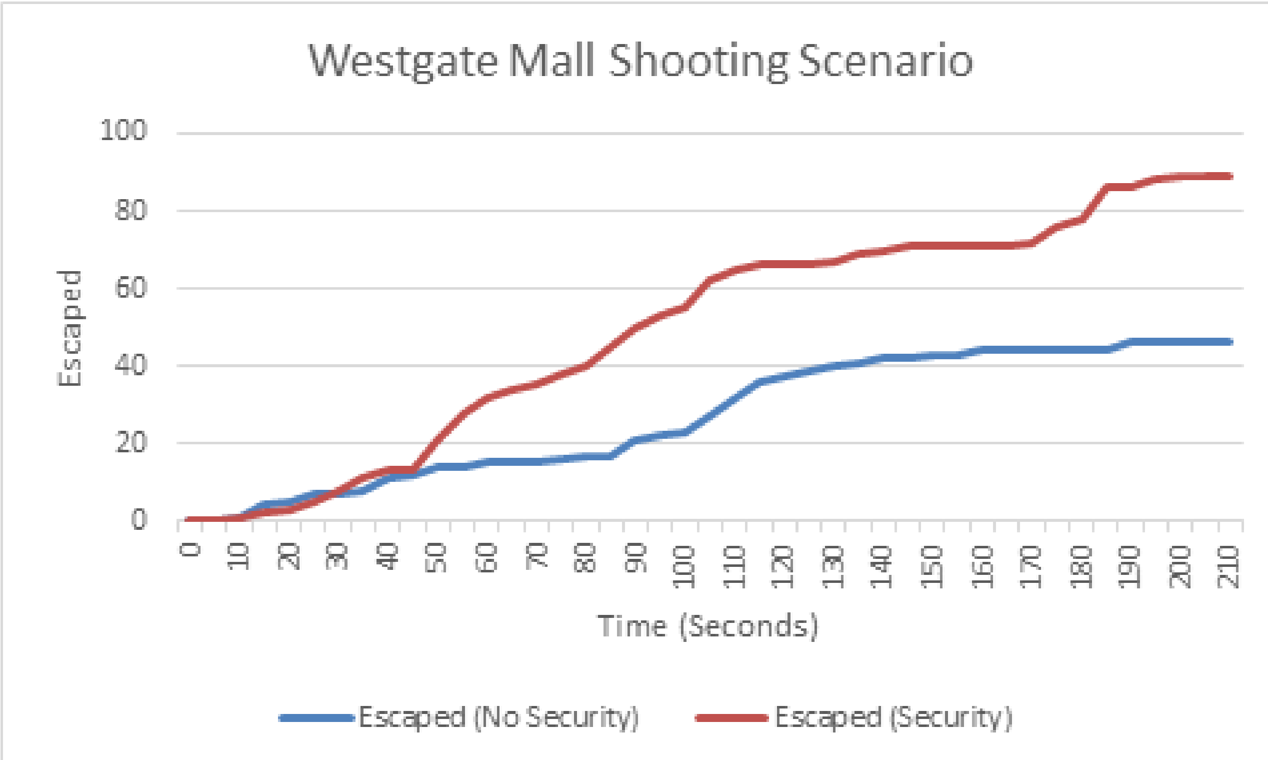


(c)

(a) Scenario A (without security officers), (b) Scenario B (with security officers), (c) graphs of the numbers of escapees over time in Scenario A and Scenario B.

2.2.6 Emergency Response Plans for Escaping from High-Rise Buildings

As terrorists and violent extremists attack vulnerable and innocent people at random, it is important to address how communities and individuals handle these traumatic situations, particularly according to vulnerable populations such as senior citizens, children, and disabled individuals (Hans and Mohanty 2006). However, in the current emergency preparedness and response systems, those populations, largely the elderly and disabled, are overlooked (Williams 2006). It has become clear that emergency plans in their current state on the federal and local level are insufficient and rarely can cope with special cases such as frail elderly, handicapped, and medically dependent individuals (Gatty 2009). Escaping from high-rise buildings is particularly challenging for elderly people and people with disabilities. This is the first indicator that emergency response teams and disaster plans need to adjust their protocols to better support those populations to quicken recovery, lessen emotional trauma, and save the lives of citizens.

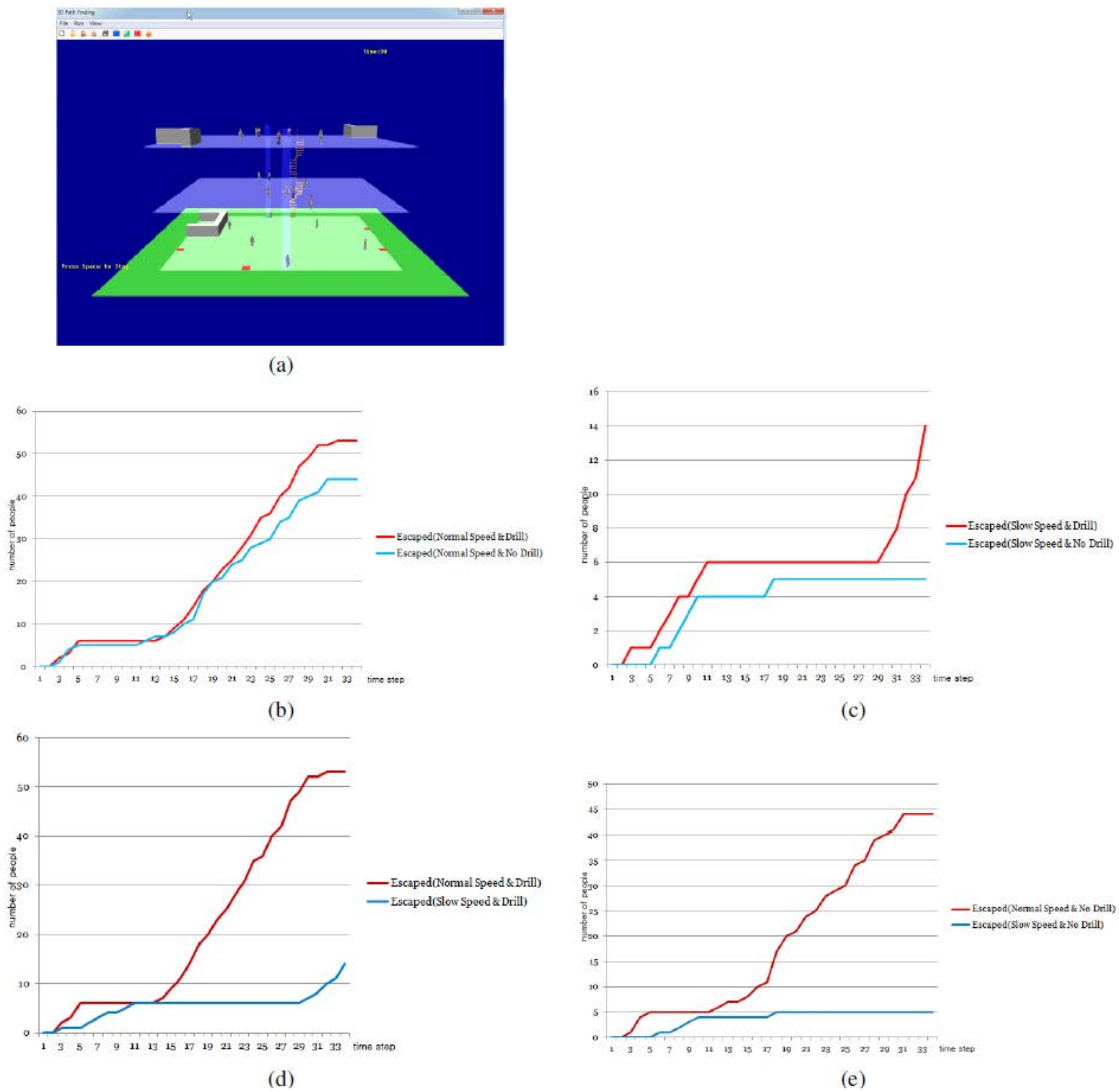
Since terrorists attacked the World Trade Center on September 11, 2001, counter-terrorism and response now need to prepare for other terrorist attacks on high-rise buildings (skyscrapers). According to the World Trade Center evacuation study (Gershon et al. 2007; Gershon 2011), one of the factors that affected evacuation was preparedness planning. Thus, the effect of fire drills was explored in the following experimental scenario (Scenario C).

The extension of the *GENIUS* framework provides an ability to construct multiple-story high-rise buildings and place stairs (fire escapes) and elevators at any location of the floor. Exits can be located on the ground floor. Different kinds of agents can be placed on each floor and a scheduled event (fire or gas) can be set on any spot of the floor.

In the experiments, a ten-story building was used and six people were placed on each floor. The scheduled fire was set on the tenth floor. The same number of stairs, elevators, and exits with the same locations were used for each experiment. Two different age groups were tested: young adults versus older adults. Older adults had more physical limitations than young adults in terms of walking speed and sight distance. For each age group, two experiments were conducted: one with the agents who had fire drills and the other with the agents who had no fire drills. Those who had fire drills could find stairs and exits more quickly than those who had not.

Figure 9b shows the difference between a previous fire drill experience and no experience for young adults. After thirty-four cycles, about 88 percent of the young adults who had had fire drills escaped from the building whereas 73 percent of those who had not had fire drills escaped. The difference is much bigger for the case of older adults (Figure 9c). 23 percent of the older adults who had had fire drills escaped after thirty-four cycles whereas only 8 percent of those who had not had fire drills escaped. Figure 9d and Figure 9e show the difference between young adults and older adults for both cases of fire drills and no fire drills, which is about 65 percent. It is observed that a fire drill exercise helps people find fire stairs and escape quickly. The difference between young adults and older adults in escaping from high-rise buildings is relatively big. This suggests that people who have physical limitations need better ways of escaping from high-rise buildings.

FIGURE 9. INITIAL SETUP AND PLOTS OF A TYPICAL RUN IN SCENARIO C



These figures are showing (a) the setup of Scenario C, (b) the graphs which plot the number of escapees of young adults over time in Scenario C (drills vs. no drills), (c) the graphs which plot the number of escapees of older adults over time in Scenario C (drills vs. no drills), (d) the graphs which plot the number of escapees of both young and older adults over time in Scenario C (drills), (e) the graphs which plot the number of escapees of both young and older adults over time in Scenario C (no drills).

2.2.7 Virtual Environments as a Training Tool for First Emergency Responders

After creating and verifying optimal and relevant emergency response plans and protocols with the *GENIUS* system, it is important to prepare and train first emergency responders with those plans and protocols. However, setting up physical environments for such training is often very costly and even not reusable. A virtual environment can be a good alternative to a physical one for training purposes. As mentioned above, virtual environment technologies have become affordable, portable, and easy to use. Realistic and immersive virtual environments can be created in a relatively short time. Another benefit is that they can be easily modified. They can be more immersive and realistic with surrounding sound and other sensor devices (such as haptic devices). Literature shows that these virtual environments have been used to train first emergency responders (Vincent et al. 2008; Wilkerson 2008; Andreatta 2010). In our research study, a training program for first emergency responders was developed utilizing currently available technologies. An immersive virtual environment was created using a big-screen projection. For participants' natural interactions with the virtual environment, a gesture and motion-based interaction was developed using a Microsoft Kinect device. Recently the immersive virtual environment was tested with over twenty students. After learning how to navigate the virtual environment with their walking motion and different gestures in the practice session, they all successfully navigated the environment to reach the destination. A few more tests have been done to see how the user can interact with virtual agents. This user's interaction with the immersive virtual environment and virtual agents from the first person's view is important in training because it creates presence: users feel that they are in the environment. Currently we are developing a feature in which the user can lead civilian virtual agents a certain direction or to an exit and we are still planning to conduct an extensive usability test with police officers in the near future. Figure 8 shows our current setup where the user interacts with the virtual environment.

Figure 10. The current setup of GENIUS

The user is interacting with the virtual environment using the Microsoft Kinect device.

3.0 Conclusion and Future Research

We have presented a series of research studies to develop a computational framework for counter-terrorism and public safety. It is apparent that virtual environments play an important role in the study of human behaviours and the training of first emergency responders due to their mature technologies, affordability, flexibility, and portability. The *GENIUS* framework and system was introduced with its structure (agent-based and parametric modeling) and its usage to devise emergency response plans and protocols. The experiments discussed in this paper demonstrated the applicability and usability of the *GENIUS* system.

The *GENIUS* system is currently being ported to an advanced graphics (game) engine (Unity 3D) to extend its features and accommodate more realistic/complex emergency planning. This enhanced version of the *GENIUS* system will also have a new feature of simulating police officers' control of a violent and emotionally charged crowd such as the Vancouver Stanley Cup riots in 2011. Further, we are planning rigorous usability tests that will be conducted with practitioners.

4.0 Acknowledgment

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