MODELING THE ROLE OF FEAR OF CRIME IN PEDESTRIAN NAVIGATION

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Abstract

Research studies in criminology and environmental psychology show that fear of crime can be generated in pedestrians by features of the urban environment such as narrow routes, hidden spaces, dumpsters and litter, and by threatening individuals; this fear may cause pedestrians to choose an alternate route to avoid these features. Criminologists and urban planners have devised a strategy called "Crime Prevention Through Environmental Design (CPTED)" which reduces fear of crime and crime itself through careful environmental design. A quantitative model of the role that fear of crime plays in pedestrian navigation has been developed based on these findings from criminology research. In the course of validating the model, we constructed a virtual environment (VE) that resembles a well-known fear-generating area where several decision points were set up. Each decision point tested the reaction of pedestrians to environmental features thought to generate fear of crime. A total of 60 human subjects were invited to navigate the VE and their choice of routes and comments during the post experimental interviews were analyzed using statistical techniques and content analysis. From our experimental results, we not only validated our pedestrian model but also discovered new pedestrian behaviour in making a choice of routes. From this research, we propose a new enhanced model of the role of fear in pedestrian navigation. This research also shows that virtual environments can be a useful tool in criminology research.

To my wife and children: Without their understanding and support,
this work would not have been possible.

“There is no fear in love.
But perfect love drives out fear,
because fear has to do with punishment.
The one who fears is not made perfect in love.”

— 1 John 4:18 (NIV)

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Chapter 1

Introduction

The mode of human transportation that has the longest history is traveling on foot or walking. Although people use transport facilities such as cars, trains, or airplanes for their long trips, most of them still walk for a short distance (unless Segways become a common means of transportation, which we suspect). Since human civilization began, urbanization increased and urban environments began to play an important role in human life. In particular, pedestrians who travel on foot in the environment were influenced by these changes. Many environmental features such as high-rise buildings, parks, attractions, sidewalks, traffic lights, cars, volume of traffic, and many others affect pedestrian behaviour. Researchers from different disciplines such as computer animation, artificial intelligence, physics, and other interdisciplinary areas have tried to model pedestrians and their navigation for decades. Many researchers developed their pedestrian models as autonomous agents with built-in behavioural rules and cognitive architectures [70, 97]. Some focused on a single pedestrian's natural walking movements [3], whereas others were more interested in the interactions and emergent behaviour of multiple pedestrians in the multi-agent systems [85]. Some physicists applied "social forces" to their pedestrian agent model, which is similar to equations of motion in Newtonian mechanics [49]. Others used cellular automata to simulate pedestrian traffic [16, 61, 122, 133].

However, most of these research projects have aimed to create realistic computer animation of pedestrian movements or realistic behaviour in simulated environments—there have been not many studies that sought to validate the findings of the social science research. Currently many social science researchers are beginning to seek ways to visualize or simulate their findings using available technologies. Our research study meets the demands of both applied science and social science communities, particularly, computer science and criminology.

In this thesis we present the development of our pedestrian agent model based on the findings of the social science research and the validation of the model using a virtual environment. Many research studies in criminology and environmental psychology have discovered that people are afraid of certain features of the urban environment such as narrow passageways without escape routes, hidden spaces created by corners, tall bushes, and garbage dumpsters. They also fear confrontation with potential offenders who might be hiding themselves using these environmental characteristics. If they really sense possible dangers or risks, they take alternative routes to reach their destinations. Crime Prevention Through Environmental Design (CPTED) is a strategy that has been developed to reduce the fear of crime and crime itself by careful environmental design. We employed these findings in our pedestrian agent model and simulation system.

The pedestrian agent model was developed as a relatively simple model with the intention that it was to be tested against real human pedestrians. The model was simulated in a simulation system and showed behaviour that reflects the earlier findings. Although the pedestrian model was developed based on the social science research studies, it was necessary to validate the model by testing it against real human pedestrians and their behaviour. There were many practical issues in experimenting with human subjects in a real-world environment such as too many uncontrollable variables, ethical problems of placing the subjects in a dangerous environment, and cost and time involved with this research. We then decided to construct a virtual environment (VE) resembling a well-known fear-generating urban area. In the VE, five decision points were set up with the distinct environmental features that we wanted to test. A total of 60 subjects were recruited to navigate the VE, making decisions at the decision points. We collected data describing their choices, demographics, and comments during post experimental interviews. The data was analyzed using statistical techniques and content analysis. As a result, some of earlier research findings were confirmed and some new findings were discovered

From the experimental results and analysis, we gained new insights into pedestrian behaviour and we are now in a good position to develop a better and more complicated pedestrian model that reflects the behaviour of real pedestrians in an urban environment. Following discussion of our results we present some of the features and factors that should be considered in the future development of a realistic pedestrian agent model. We also found that a VE can be a useful tool and new methodology for many different social science research studies, especially in criminology research.

Chapter 2

Background

> *"Dull, inert cities, it is true, do contain the seeds of their own destruction and little else. But lively, diverse, intense cities contain the seeds of their own regeneration, with energy enough to carry over for problems and needs outside themselves."*
>
> *—Jane Jacobs, The Death and Life of Great American Cities, 1961*

The research that we have conducted integrates various concepts and research results from multiple disciplines such as criminology, virtual reality, artificial intelligence, and cognitive modeling. In this chapter, we introduce these concepts and research findings so that the subsequent chapters may be seen in appropriate context.

2.1 Crime Prevention Through Environmental Design (CPTED)

Crime Prevention Through Environmental Design (CPTED) is a multidisciplinary approach to deter criminal behaviours by careful environmental design, which reduces the occurrence and fear of crime, thereby improving the quality of life. A brief history of CPTED and other related concepts are discussed below [60].

2.1.1 Short History of CPTED

Humans and their surrounding environment have mutually influenced each other throughout history. The relationship between man and environment is mentioned in the early history of mankind. The very beginning of the Old Testament of the Bible begins with the story of a beautiful garden where the first humans live. However, the humans are tempted by an element of their environment, which is a fruit of a tree of the knowledge of good and evil, and driven out of the garden. Just on the surface level, the story consists of humans, the environment, and crimes.

The structure of the man-environment relationship has changed at different stages of history. At first, the natural environment influenced human activity and life-style. For example, cave men lived in caves to protect themselves from their surrounding unfriendly environment such as cold weather or wild beasts. As humans became civilized, they actively cultivated their surroundings, changed the physical structure of the environment and built their own environments. As a result, man-made environments began to play an important role in human societies. These man-made environments embedded the culture and religion which were a part of the daily life of the local people.

In modern times, urban environments are becoming more important than before since a high percentage of the population live in cities. According to the database of World Resources Institute (www.wri.org), 48.7% of the world population lived in an urban area in 2005. In North America in the same year, 80.7% of the total population were living in urban cities. The growth rate of the rural poplulation was -0.6% whereas that of the urban population was 1.4% in North America in 2005. As the urban population grows, many problems are ocurring such as lack of secure housing, water, sanitation, and power. Slums spring up in urban areas in developing countires. A billion people which is approximately a sixth of the world's population lives in slums, 90% of them in developing countries according United Nations Population fund report in 2007. In this kind of urban environment, crimes are one of the major problems that society has to solve. According to a Statistics Canada report, crime rates in 2005 are higher in urban areas than in rural areas.

Because so much human activity takes place in an urban environment, many researchers have begun to study the influence of the urban environment on people's behaviour and life-style.

Jane Jacobs was not formally educated in the area of city planning, nor did she hold the title of urban planner. But she built up her own experiences and observations about cities while she was working with many different jobs in New York City. She found that government polices regarding urban planning and urban renewal strategies did not meet the needs of the people, often destroying urban diversity and vitality. She argued in her influential book "The Death and Life of Great American Cities" that the lack of diversity or mixed-land use would create many different kinds of urban problems such as the cessation of economic growth, slums, and crimes [59]. Another big issue to which Jacobs called attention was the problems caused by isolating low-income people in high-rise apartment complexes in empty space. The lack of embedded business in these areas and closed-in hallways and elevators became a hotbed for crimes and bad morale for the residents. She proposed that a mixed land use plan would provide natural surveillance on the streets as well as attract people. Despite her unrelated background, her work has greatly influenced urban planners and architects and caused them to see cities in a new perspective.

Another person who also happened to observe people in New York City was William Whyte: he was known as a "people watcher." While working with the New York Planning Commission in 1969, Whyte and his research assistants used direct and systematic observation of people's behaviour in urban settings through still cameras, time-lapse movie cameras, and grid notebooks [124]. Originally his "Street Life Project" was expected to last just a few years. But he ended up working on it for 16 years. His work, however, paid off since he could describe the urban life in an objective and measurable way. He explains how different urban settings influence peoples' behaviours such as the width of sidewalks and the position of benches. In fact, his book, "The Social Life of Small Urban Spaces" and the accompanying film show architects and urban planners which urban settings work and which others do not work.

Following these ideas, architects and criminologists began to investigate how environmental design can reduce crimes and fear of crime.

The architect Oscar Newman proposed the concept "defensible space" to control and mitigate crime and delinquency through environmental design [80]. While Newman was teaching at Washington University in St. Louis, he witnessed the failure of highly concentrated public high rise housing projects even though they were designed by renowned architects. Mostly occupied by single-parent, welfare families, the design of the buildings did not work at all. The elevators, laundry, and community rooms were vandalized, and the garbage was piled up around the garbage chutes. The buildings were never fully occupied. He found out that one of the reasons for this disaster was that the residents did not have ownership of public spaces. Across the street from this project was an older, smaller, row-house (town-house) complex. It had been fully occupied and trouble-free while the project next to it was failing. Newman discovered the significance of the physical differences in the survival of one area compared to another one that was destroyed. He then researched the effects of different housing forms and building types on residents' ability to control areas and streets. Moving from single-family houses to walkups (town-houses) to high rises, he found that crime rates proportionally increase due to the residents' disproportionally less private spaces and less ownership. From this study, he concluded:

> *"Regardless of the social characteristics of inhabitants, the physical form of housing was shown to play an important role in reducing crime and in assisting residents in controlling behavior in their housing environments"*

The findings of his other research show that building size has a statistically significant direct causal effect on residents' use of public areas, social interaction with their neighbors, sense of control over the interior and exterior public areas, and fear of crime. Another significant factor that has a causal effect on fear of crime, community instability, and crimes is the socioeconomic characteristics of residents. Newman's approach to crime prevention includes the concepts of territoriality, surveillance, image, and safe zones. His method was picked up by the U.S. government, private corporations, and academics and applied to their research and applications.

Criminologist C. Ray Jeffery is known as the originator of the term "Crime Prevention Through Environmental Design" (CPTED) [60]. Unlike Newman's approach which emphasizes the physical environment, Jeffery's approach in crime prevention is more comprehensive and interdisciplinary across many different disciplines such as biological and social ecology, urban geography, psychological learning theory, urban planning, and criminology. In particular, his original notion of CPTED was based largely on the utilitarian models of Jeremy Bentham and on experimental psychology and Skinner's stimulus-response models [96]. He argues that behaviour is the focus of crime prevention. He employs the basic learning theory from psychology that a stimulus from the environment shapes and controls behaviour. But he strongly proposes that we reinforce desirable behaviour rather than punishing undesirable behaviour indicating that punishment does not work. Creating healthy, affective environments is important for the development of the infant. He does not deny the application of Newman's ideas but suggests that they should be done within the framework of total urban planning, considering all other aspects such as ecology and crime.

As Jeffery noted, CPTED that is known and practiced today is a closer adaptation of Newman's defensible space than of Jeffery's original ideas, even though it employs elements of both. Since the original CPTED concept came out, it has been expanded, developed, and incorporated with other place-based strategies such as situational crime prevention and environmental criminology. CPTED consultants have trained law-enforcement personnel in the use of CPTED strategies at local and national levels. Furthermore, the training and awareness of CPTED has been accelerated by terrorist attacks across the globe because CPTED strategies for common crimes can also be applied to anti-terrorist planning. The principles of CPTED include:

- natural surveillance;
- access control;
- territorial reinforcement;
- proper placement of land uses.

2.1.2 Broken Windows Theory

James Wilson and George Kelling suggested the "broken windows" theory which was added as a CPTED strategy [129]. In their original paper, they emphasized maintenance of order at the community level to reduce the fear of crime among the members of the community as well as crime itself. Disorder and crime are usually linked at the community level. If a window in a building is broken and left unrepaired, all the rest of the windows will soon be broken because one unrepaired window is a signal that no one cares, and breaking more windows costs nothing. And the situation gets worse with worse crimes occurring. One untended behaviour or property can lead to the breakdown of community controls. Wilson and Kelling thus claim that controlling low-level anti-social behaviour and petty crime will prevent major crime and keep the whole community healthy. In the course of doing this, they say that the role of the police, which is maintaining order at the community level, is important. They argue that the police should communicate with their community and keep its order, not just focusing on individual crimes.

2.1.3 Situational Crime Prevention

Situational crime prevention developed by psychologist and criminologist Ronald Clarke aims to reduce crime by reducing specific crime opportunities [17]. These crime opportunities depend on five factors: risk, effort, reward, provocation, and shame and guilt. Offenders consider all these factors to decide whether or not they would commit specific crimes. This rational choice model is supported by many small, specific criminal events. 25 techniques employed in situational crime prevention aim to increase the risks and effort, and reduce the rewards, provocations, and excuses of committing the crimes. They include the ideas of CPTED such as natural surveillance, fixing broken windows (maintenance of order), territorial reinforcement, and access control as well as other techniques such as reducing emotional arousal and control drugs and alcohol. Obviously, environmental components play an important role in these techniques. A good environmental design can reduce the opportunity for criminal events.

2.1.4 Environmental Criminology

A crime is constituted by the four elements: a law, an offender, a target, and a place. Without even one of these, a criminal incident will not be established. Unlike the traditional approach that focused only on one dimension, which is the offender, environmental criminology is the study of the fourth element (dimension), the place, even though its intersection with the other elements is considered. Greatly influenced by the ideas of Jeffery (CPTED) and Newman (defensible space) that the modification of specific features of urban design and architecture would reduce crime, Paul and Patricia Brantingham pioneered the contemporary environmental criminology which separates from the earlier research that had flaws [11]. The Brantinghams and other environmental criminologists employed techniques and knowledge from many different disciplines such as urban planning, geography, environmental psychology, and computer science in order to understand any particular crime. They suggest that by analyzing the temporal and spatial data of crimes, spatial patterns of the crimes and behavioural patterns of the offenders can be discovered. Based on these patterns, the Brantinghams developed a geometric model of possible crime sites which is influenced by the actual distribution of opportunities, urban form, and offender and victim mobility. They argue that the behaviour of criminals is not random and that by investigating urban structure and how people interact with it, it is possible to predict the spatial distribution of crime. In fact, this idea has been computerized using crime mapping technology. There are three levels of analysis in Environmental Criminology: Macro-analysis which involves studies of the distribution of crime between countries, states, provinces, or cities, meso-analysis which involves the study of crime within the sub areas of a city or metropolis, and micro-analysis which involves the study of specific crime sites, focusing on building type, landscaping, lighting, and so on.

2.1.5 Other Related Concepts and Trends

Space syntax includes a set of theories and techniques for the analysis of spatial configurations, developed by Bill Hillier, Julienne Hanson, and their colleagues [51]. To represent and analyze relationships between constructed objects and (urban) spaces, space syntax uses maps, graphs, and measures, so that the relative connectivity and integration of the objects and spaces can be discovered. It provides a mathematical logic that enables connections to be made between spatial and social information such as the flow of pedestrian/vehicular movement and crime in urban spaces. Space syntax has been used in the designs of museums, hospitals, and airports where wayfinding is an issue. Simon Shu and Bill Hiller used space syntax to investigate connections between property offenses and housing layout [52]. They argued that the results of their research were contradictory to Newman's concepts of territoriality and natural surveillance. However, later research done by other researchers using space syntax shows favourable results for Newman's ideas [111, 130]. And much empirical evidence does not support the arguments of Shu and Hiller. For example, they argued that increasing pedestrian traffic would help make space safer. But it could lead motivated offenders to see targets of interest and thus increase crime rates. Use of space syntax in investigating crime needs further research.

New urbanism is an American urban design movement mainly led by architects. After World War II, many people in the U.S. began to live in suburban communities. Most of them have to use cars to go to work and shopping malls. New urbanists advocate the building of small-scale, open, walkable, and permeable communities like European cities. These communities should contain a diverse range of housing and jobs, much like the ideas of Jane Jacobs, mixed land uses. Even though this seems ideal and neighbour-friendly, from the criminological point of view, it can have hidden costs because many studies show that communities with permeability and mixed land uses are more vulnerable to certain types of crimes (property crimes). Like space syntax, people should be informed about the possible consequences of their choice of a community based on new urbanism.

2.2 Fear of Crime

Fear of crime is a very practical and prevalent issue for those who live in today's society. Even though a high level of *fear of crime* does not always mean that there is a high chance of being victimized, it still lowers the quality of life. *Fear of crime* research has been continued for a few decades in many different disciplines such as criminology, sociology, gerontology, environmental psychology, and so on. In fact, many CPTED strategies are devised to reduce not only crime but also the *fear of crime*. However, due to the nature of fear which is difficult to define and measure, there have been debates about methodological issues in the *fear of crime* research. In this section, we survey the previous research on *fear of crime*, paying special attention to the relationship between environmental features and *fear of crime*.

2.2.1 Definition of Fear of Crime

Despite the fact that *fear of crime* research has actively been carried out for the last 25-30 years, the term "*fear of crime*" has been abused and is not standardized. Many researchers have made their own definitions of "*fear of crime*." For example, Conklin defined it as a"feeling of personal unsafety in the community" [19]. Ward referred it to "a lack of a sense of security and/or feelings of vulnerability" [119]. Garofalo understood it as an "emotional reaction characterized by a sense of danger and anxiety produced by the threat of physical harm...elicited by perceived cues in the environment that relate to some aspect of crime for the person" [38]. This definition is similar to that of Ferraro, which is "an emotional response of dread or anxiety to crime or symbols that a person associates with crime" [34]. Pain, Williams, and Hudson conceptualized *fear of crime* as "the wide range of emotional and practical responses to crime and disorder which individuals and communities may take" [82]. Many other researchers, however, did not articulate their concept of *fear of crime* and adapted the concept to whatever measure they used. But it turns out that articulating the notion of *fear of crime* is important because it helps in deciding what to measure as an indicator of *fear of crime*.

2.2.2 Measuring Fear of Crime

Depending on the definition of the *fear of crime*, various measures might be used as an indicator for it. If the *fear of crime* is understood as an emotional response to possible victimization in a certain crime, we have to measure an indicator of such emotion. In fact, Ferraro and LaGrange tried to measure that indicator, not something else [34]. They first articulated the definition of the *fear of crime* and distinguished "fear" of crime from judgments (perceived risk) and values. Judgments are a cognitive evaluation of probabilities of becoming a victim of crime. This is assessing (interpreting or judging) the risk. Values are a concern one has about crime, either for one's self or for others, which are the degree of concern about or tolerance for crime. Fear is an affective measure in response to the crime. They argued that the commonly used survey questions regarding the *fear of crime* do not differentiate these three concepts. Some of the common survey questions are:

- How safe do you feel or would you feel being out alone in your neighbourhood at night?
- Is there any area right around here-that is, within a mile-where you would be afraid to walk alone at night?

These questions do not measure the indication of an emotional response to crime, but rather an estimate of perceived risk. Ferraro and LaGrange thus implemented their own survey questions: one kind is about perceived risk, the other, the *fear of crime*. However, there is an inherent problem in measuring fear from questionnaires or interview data collection. When people are asked with the survey questions, they imaginatively rehearse with imagined fear. This is not the pure reflection of emotional experience. On the other hand, having an experiment with people in the real world environment may not be ethical.

In the tradition of the *fear of crime* research, many scholars blend cognitive and affective *fear of crime* measures. In addition, some scholars use behavioural measures as an indicator of the *fear of crime* [100, 33, 42]. Survey participants are asked to indicate the actions that they would take to prevent possible victimisation [128]. Those who advocate the use of the behavioural measures take the perspective that what people do is a better indicator of their fear level than what they say.

The definition of *fear of crime* that we employ in this research is close to the notion of Pain, Williams, and Hudson, which covers not only emotional responses but practical (behavioural) responses too. This definition helps us to measure the *fear of crime* in terms of people's behaviour (choice).

2.2.3 Fear of Crime Matrix

The *fear of crime* matrix is well known to the *fear of crime* research community. It shows the relationship between crime levels and *fear of crime* in different areas and suggests strategies to solve local *fear of crime* issues. Figure 2.1 shows such relationship and strategies.

Figure 2.1: Fear of crime matrix

Source: Adapted from the graph on the British government's Crime Reduction website at www.crimereduction.gov.uk/fearofcrime0216.htm.

2.2.4 Predictors of Fear of Crime

According to the literature, it is interesting to note that in many cases the level of fear does not correlate with the actual risk of victimization. However, there are numerous factors that are related to the *fear of crime* such as gender, age, past experiences with crime, ethnicity and culture, and other variables.

Among these factors, gender has been proved to be the strongest predictor of the *fear of crime* [37, 67, 127, 126]. This relationship has been consistent across many different studies, showing that women have a higher level of fear than men although women have been victimized less than men. There have been many studies on why women are more fearful than men. Some have suggested that women's irrationality might be one of the reasons, which has provoked feminist researchers [72]. Others have explained that women are more fearful because they are more vulnerable physically and socially [90, 103]. Others have argued that women's fear comes mostly from their vulnerability to sexual aggression: women are ten times more likely to be sexually assaulted than are men [22].

Age is the second factor that is strongly related to the *fear of crime*. The general conclusion from the related work is that as people grow older they tend to be more fearful [37, 67, 127, 42, 114, 126]. Like gender, research findings show that the older people's fear level is inversely related to their actual risk of victimization. Some researchers explained the reason for their fear is that the older people are physically frail and lack of financial and social resources to rely on [34]. Unlike gender, older people's *fear of crime* has various causes, depending on different types of crime [31]. In the cases of mugging and break and enter, they are more afraid than younger people. But in cases of sexual assault and stranger attacks, the younger people tend to be more fearful than the older people.

Many research studies have investigated whether those who have experienced crime previously have the higher level of the *fear of crime*. But their findings are not consistent. Some findings show that those who already have experience with crime are more fearful than those who have not [102, 95] whereas other studies have discovered the the opposite results with the reason that those who have been victimized would assess the nature of crime more realistically, thereby reducing *fear of crime* [131]. The reason for this inconsistency is that there are so many factors that play in the relationship between the past experiences and the *fear of crime* such as types of crime, the degree of the damage caused by the crime, each individual's personality, and so on.

According to the British Crime Survey in 1994, different ethnic groups showed different levels of fear depending on different types of crime. In cases of harassment, burglary, rape and mugging, the Asian group expressed the most fear, the Black, the second, and the White showed the least fear. For the crime of theft from a car, the Black group showed the most fear, the Asian, the next, and the White again had the lowest level of fear. For the question of simply feeling unsafe, while the Asian group was again the highest, and the White was slightly higher than the Black [54], other studies showed slightly different results [118, 31]. The general consensus is that the White group generally shows the least fear in any type of crime.

Fear of crime research has investigated other variables such as income levels, educational levels, marital status, and so on. But these variables are not as salient as the ones mentioned above. For example, some researchers found that the education level is inversely related to the *fear of crime* [67] whereas others did not find any significant relationship [74].

It is commonly believed that mass media such as newspapers, radio, and television affect people' *fear of crime*. Crime News reported by mass media mainly focuses on serious and sensational crimes like murders, muggings, and violent assaults [116] and tends to portray society as being more vulnerable to crime than the actual situation. Research done on this subject shows that there is no simple relationship between mass media and *fear of crime* [48]. In the case of television and *fear of crime*, some research shows that television program types, neighborhood context, and demographics of viewers are related to the *fear of crime* [30]. Violent crimes shown in the local news and reality crime programs increased viewers' *fear of crime*. Those who live in the neighbourhood of high crime rates (or believed to be high crime rates) are more affected by television crime news. Significant relationships between television and fear are found for women, non-victims, low income, and younger respondents. In the case of newspapers, people tend to have higher *fear of crime* when they read news about the crimes that are local, sensational or random and have a high proportion of the pages of newspapers [47]. If the locations of the crimes are far from their neighbourhood, people feel safe.

2.2.5 Environmental Cues and Fear of Crime

Some environmental cues serve as signals interpreted by individuals as threats. These cues are interpreted as either social incivility (disorder) or physical incivility [68, 94, 101]. The signs of social incivility can be prostitution, drug dealing, panhandling, public drunkenness, or homelessness. Teenagers hanging out around street corners can also be seen as threatening [10, 86, 83]. The signs of physical incivility can be litter, broken windows, abandoned storefronts, unkempt lots, graffiti, or vandalism. Almost all related studies report that there is a strong relationship between incivility and *fear of crime*. However, social incivilities seem to be more predictive of fear than physical incivilities. In other words, untended people generate more fear than untended properties.

There are certain environmental structures or space configurations where people might feel fear. Goffman's study shows that people constantly monitor their environments for signs of danger [41]. One of such signs is "lurk lines" which mark off zones that are beyond or behind the individual's line of sight. Some examples of lurk lines are dumpsters in alleys, parked vehicles on the street, shrubs, and signs [120]. Once these are seen as a danger, people try to escape from it. Fisher and Nasar have studied students' fear in the campus environment using the concepts of refuge (concealment), prospect, and escape [35]. A refuge is a hiding place or a place of concealment for potential offenders. For example, alcoves, bushes/shrubs, around sharp bends in passageways, and any blind spots can be hiding places for the offenders. These refuges increase people's fear. Prospect is the view of a potential victim. Open prospect provides potential victims enough view to know what is going on within the environment; thus it reduces *fear of crime*. On the other hand, blocked or limited prospect increases fear in them due to the uncertainty of the situation. Escape is the possibility for victims to avoid dangerous situations or the possibility of connection to others for help. The degree to which a space provides an opportunity for escape influences people's feelings of safety. For example long, narrow passageways without escape routes generate fear in possible victims.

The research done by Herzog and Flynn-Smith has focused on the relationship between perceived danger and the several characteristics of urban alleys such as setting care (how well cared-for), mystery (curiosity to know more by going deeper), shadow, curvature, width, and length [50]. Using photographs of various kinds of the urban alleys, Herzog and Flynn-Smith asked research participants how they feel about those characteristics of the alleys. Their findings show that alley width is negatively associated with perceived danger, that is, narrow alleys are seen as more dangerous. Setting care is negatively related to perceived danger. Well-maintained, orderly alleys with good surveillance make people feel safe, whereas alleys with no care generate fear in them. This result is in accord with the theory of "broken windows." In the case of shadow, the more shadow occupies the alleys, the more people feel them to be dangerous. Mystery plays as a positive predictor of both preference and danger. People feel curious about the unknowns in the deeper place of the alleys. At the same time, they also feel it is dangerous to go in. Herzog and Flynn-Smith think this paradoxical role for mystery seems to be context dependent.

Lighting is another element closely related to *fear of crime*. Hanyu used two sets of photographs on the same places for his research: one set was taken during day light, the other, after dark [43, 44]. Research participants rated these photographs based on their feelings. The result suggests that even though people see the same urban scenes, they feel more fearful after dark. Hanyu argues that uniformly bright lighting for deserted places reduces the feeling of fear.

Table 2.1: Fear Generators

Characteristic	**Fear Generator**
Limited knowledge of what is around	Lack of prospect Blind spots created by corners Lack of lighting Hiding places
Presence of ”threatening” people, that is, people who are seen as different and potentially aggressive	Teenagers Panhandlers Intoxicated people People of different ethnic groups
Signs of trouble	Litter, trash Garbage dumpsters Graffiti, writing on the wall Metal bars on windows and doors Alarms
Lack of choice in routes on foot	Single pathways without escape routes Requirements to work at specific locations Requirements to travel a specific way (bus stops, tunnels to transit) Requirements to enter unknown space behind a solid door
Isolation	No one near whom you know No one who could be witness or help

Brantingham and Brantingham categorized the *fear of crime* into five factors [12]:

- Direct fear of another person.
- Fear of being alone.
- Fear at night, in the dark.
- Fear in unknown areas.
- Fear of encounters with “scary” people.

They discovered that *fear of crime* is increased by perceived personal physical vulnerability, increased isolation from known others, and lack of control over the situation. Table 2.1 is the adapted version of the table of fear generators that they made.

2.3 Social Science Modeling and Simulation

In this section, we briefly review modeling and simulation in general. Then we survey how modeling and simulation have been used in social science research. We mainly focus on computer simulations.

2.3.1 Modeling and Simulation in General

One of the definitions of simulation is driving a model of a system with suitable inputs and observing the corresponding outputs for the purposes of prediction, performance, training, entertainment, education, proof, and discovery [4]. By creating a model, we capture the structure of a system and then use a simulation to test it. A model is a simplified version of something complex used in analyzing and solving problems or making predictions. Thus simplification is an important part of the modeling process. When we simplify something, we have to decide what we are to include and what we are to exclude. Theoretically, the things that we can exclude should not affect the outputs of simulations whether or not they exist in the model. For example, when we simulate the orbit of the earth which goes around the sun, we do not have to consider the things that are on the surface of the earth such as people, mountains, seas, buildings, and so on because they would not affect the simulation outputs. However, when we simulate the falling of a bird feather, whether or not we include air in our model generates totally different outcomes of the simulation. We, therefore, should be careful to choose the elements that should be included in simulation models in the process of simplification.

Two other important processes in developing simulations are verification and validation. Verification is the process of ensuring that the model (conceptual model) has been translated into a computer program (computer model) with sufficient accuracy. Validation is the process of ensuring that the model is sufficiently accurate for the purpose of the simulation. Validation can be done by comparing data from the real world system with data from the simulated system.

The reasons we use simulations instead of experimenting with the real world itself include:

- It is often not feasible to test the real system.
- It is difficult to control all experimental variables with the real system.

- Experiments on a simulation model can be repeated exactly while it is very difficult to repeat the same, exact experiments with the real world. This is an important aspect of scientific research.
- Simulations can be used to study objects or phenomena that are dangerous, such as the evacuation procedures for an approaching hurricane or possible offenders' interactions with possible victims.
- We can simulate the model of a system that does not exist in the real world. For example, we can simulate the societies of the Paleolithic period or even those of the future [13].
- The speed of simulations is controllable. For example, by making a simulation system run fast, it is possible to get results in a matter of hours and days, which would normally take years in a corresponding real system.
- Simulations are likely to be cheaper than experiments with the real world.

2.3.2 Models and Simulations in Social Science Research

In recent years, models and simulations in the social sciences have become popular. One of the reasons is that models and simulations are well adapted to developing and exploring theories concerned with social processes. Models and simulations capture and allow one to visualize such dynamic social processes. Another reason is that models and simulations can help with understanding of the relationships between the attributes and behavior of individuals (the micro level) and the global (the macro level) properties of social group. In other words, it is possible to use simulations to investigate emergent phenomena [39]. As Axelrod states, models and simulations are the third way of doing research, in addition to deduction (start from assumptions and test their consequences) and induction (the development of theories by generalizing observations)[4]. Simulations start with a model based on a set of assumptions (deduction), but use an experimental method to generate data which can be analyzed inductively.

It is interesting to note that mathematics has never become widespread in the social sciences except in some parts of econometrics. We can think of several reasons why computer models and simulations are more appropriate for formalizing social science theories than mathematics [109]. First, programming languages are more expressive and flexible, and less abstract than most mathematical techniques at least for those who are non-specialists. Second, programs deal more easily with parallel processes and processes that do not have a well-defined order of actions like systems of mathematical equations. Third, programs can easily be made to be modular, so that major changes can be made in one part without the need of changing other parts of program. This can be more advanced when we use the object-oriented paradigm. Finally, it is easy to develop heterogeneous agents in simulation systems such as people with different perspectives on their social worlds, different stocks of knowledge, different emotional tendencies, and so on. This is difficult using mathematics.

As stated earlier, simulation of models can be another method of doing research. There are other specific methods of doing social research such as analytic methods. It is important to know that the target or subject of social science research is mostly dynamic. It changes over time and reacts to its environment. This requires that the model should also be dynamic. We can use an analytic method to model such a dynamic entity, reflecting the dynamic changes of both the structure and behavior of a model over time. However, when the specification of the model is nonlinear, it is very difficult to model using an analytic method. In such cases, simulation of a model is often the only way of doing research.

Monte Carlo simulations are often used when it is not feasible or possible to calculate an exact result with a deterministic algorithm [56]. They generate inputs randomly from the domain and perform a computation on them repeatedly. By aggregating the results of the individual computations, the final result can be generated. Monte Carlo simulations are often applied to physical and mathematical systems.

We can model a target using statistical modeling. The research develops a model (i.e. a set of equations) through abstraction from the presumed social processes in the target. These equations include parameters whose magnitudes are determined in the course of estimating the equations. The researcher collects some data from the real world, which are variables included in the equations. Then comparison can be done between the predicted data from the statistical model and the actual, collected data [39].

Simulations works in a similar way to statistical modeling. The way simulations work as a social science methodology is as follows: The research develops a model based on presumed social processes. This will not be an easy job because the description of the target (social phenomena which we want to model) is usually verbose and it is not easy to convert the description to a form that is useful for modeling and simulation. We need specific modeling techniques to do so. Somehow we will make a model, possibly in the form of a computer

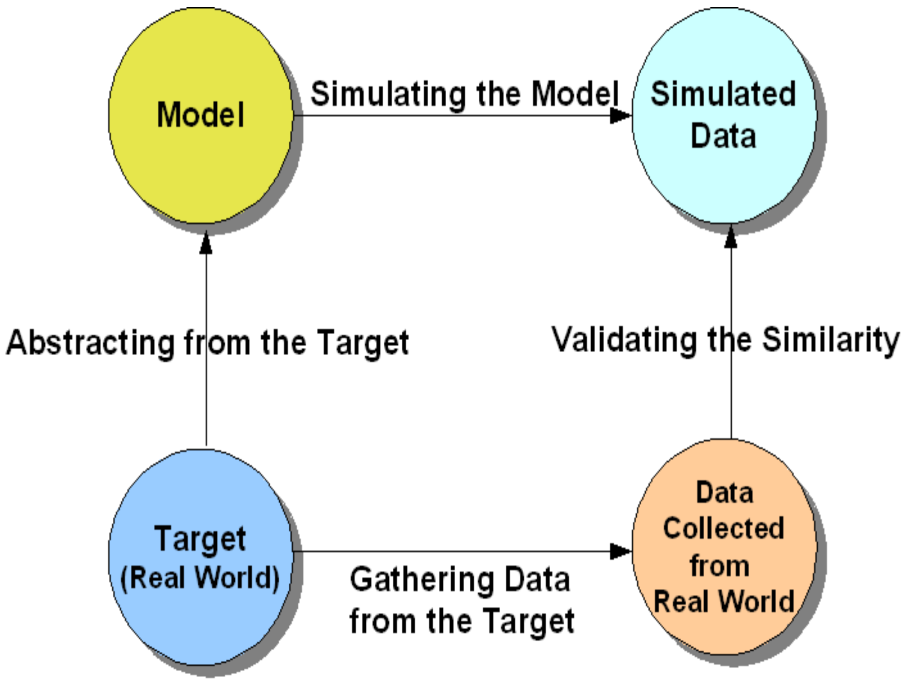


Figure 2.2: Logic of simulations

program. This model is tested in simulation and its behavior is observed, measured, and collected. These collected, simulated data can then be compared with data collected in the usual ways to check whether or not the outcomes that the model generates are similar to those produced by the actual processes operating in the social world. Figure 2.2 shows the logic of simulations as a method.

Simulations in social sciences can be used for both explanation and prediction. However, the prime purpose might be to try to understand some particular social phenomenon. Of course, we can construct simulations particularly for the purpose of predictions. In fact, if a certain simulation is quite successful in predicting a certain phenomenon, it can also provide a sensible explanation about the phenomenon. But it is still difficult predict exactly the behavior of future social phenomena due to their complexity and difficulty of finding all their attributes.

When a model for a social system is being developed, it is often not easy to find all relevant attributes of the model and their relationships among them. However, it is surprising that many famous social simulation models are much simpler than any physical or biological simulation models [5, 29, 89, 62]. There is a popular slogan among social scientists, which says, "Keep It Simple Stupid" or KISS. In other words, we do not have to make a model more detailed than it really needs to be. Sugarscape is a typical example of a social simulation that employed the idea of KISS. Epstein and Axtell [29] who developed Sugarscape say:

> *"We view artificial societies as laboratories, where we attempt to 'grow' certain social structures in the computer - or in silico - the aim being to discover fundamental local or micro mechanisms that are sufficient to generate the macroscopic social structures and collective behaviors of interest."*

As stated earlier, many social scientists are interested in the emergent behaviors which are the results of the interactions of many individuals. However it is difficult to find out what interactions among individuals result in such emergent behaviors. As Epstein and Axtell said above, many social scientists would be satisfied if they could find the fundamental micro mechanisms that generate the emergent behaviors that they would like to observe. To develop such fundamental micro mechanisms, we do not have to consider all the elements (variables or parameters) of the social phenomena, but just enough elements to generate the observed behaviours.

However, there are some social scientists who criticize the idea of KISS [28]. They argue that many scientists employ the idea of KISS just for the sake of simplification because simplified simulation models look beautiful. Those who favor the idea of KISS start their simulations with the models constructed with the least number of necessary elements. If the simulations do not work as they desire, then they add more elements to their models. Eventually they will reach the state where the simulations work as they desire. But they might still miss absolutely necessary elements that affect the behavior of the models. Thus those who are against the modeling approach of KISS propose a new approach called "Keep It Descriptive Stupid" or KIDS. In the KIDS approach, one starts with the simulation model that relates to the target phenomena in the most straight-forward way possible, taking into account the widest possible range of evidence, including anecdotal accounts and expert opinion. Simplification is only applied when the model and evidence justify this. However there is trade-off between these two approaches. Neither the KISS nor the KIDS approach will always be the best one. Rather, mixtures of the two depending on what kind of models we need to build will be appropriate.

While comparing simulations and their methodological frameworks among physics, biology, and social sciences, we have found that simulations are particularly appropriate for nonlinear phenomena in all three fields. This is because nonlinear phenomena are difficult to analyze using analytic methods while simulations can handle those phenomena relatively well. We have also found that mathematical modeling is still widely used in physical and biological simulation models whereas artificial intelligence (AI) techniques such as genetic algorithms and cellular automata are frequently used in social simulation models. The reason why AI techniques are extensively used in social simulations is that social simulations need to be executed numerous times (many generations) so that they are evolved to generate desired behaviors with the features like learning and adaptation that AI techniques provide. AI multi-agent technologies are particularly useful for the social simulations that simulate human societies where human interactions occur frequently.

2.4 Virtual Reality

Virtual reality (VR) generated a lot of public attention in the mid-1980s with the high expectation of utilizing it in people's lives. In this section, we discuss what VR is and elaborate on related technologies, its applications, and some debated issues.

2.4.1 Definition of Virtual Reality

The term "virtual reality" was coined by Jaron Lanier, CEO of VPL Research, Inc. that manufactured VR devices such as the DataGlove and the EyePhone [64]. However, the definition of what VR is has evolved over the past 20 years. At the beginning of the active development of VR in early 1990s, the definition of VR was technologically oriented. For example, Krueger referred the term VR to *"three-dimensional realities implemented with stereo viewing goggles and reality gloves"* [64]. However, technology is always changing and a change of this kind of definition over the time is inevitable. The more solid and constant way of defining the term VR would be based on human experience, not ever-changing technology. One important concept is that of "presence." Presence is the sense of being in an environment, and is an individual and context-dependent user response [106, 9]. In other words, presence is the experience of "being there." Some researchers distinguish between presence and telepresence. Presence is experiencing both the physical environment and the environment presented via the medium whereas telepresence is the extent to which one feels present in the mediated environment only [106]. However, it seems that these two terms are used interchangeably nowadays. Using the concept of presence, virtual reality can be defined as a simulated environment in which a user experiences presence. Since presence is a subjective psychological experience, a single user might experience different levels of presence, depending on the user's state of mind, past experiences and other factors, even though he or she uses the same VR system [9].

Another term that is used confusingly with the term presence is "immersion." Unlike presence, immersion is the objective level of sensory fidelity that a VR system provides [9]. Thus, immersion is objective and measurable–we can say that one system is more immersive than another. Some have expressed immersion as vividness or realness [106, 78]. For example, the level of visual immersion that a VR system can render depends on many different components such as field of view (the size of the instant visual field), field of regard (the total size of the surrounding visual field), display size, display resolution, stereoscopy, head-based rendering, lighting, frame rate, and refresh rate. These components are controlled by hardware and software. The level of immersion can be increased by adding other perceptual systems such as the auditory system, the haptic system, the taste-smell system, or the basic orienting (maintaining body equilibrium) system [106]. Other important terms related to VR are interactivity and navigation. Interactivity is the degree to which a user can influence the form or content of the mediated environment in real time. Navigation is the ability to move around and explore the mediated environment [117]. To enhance these two features in VR, high-end hardware equipment is needed.

Suspension of disbelief is a person's willingness to accept as true things that are not real. This idea is originated from the poet and philosopher Samuel Coleridge [18] in the context of the creating and reading of poetry. For example, an audience overlooks or ignores the limitations of science fiction movies, video games, or VR simulations, so that they can accept those premises. This idea is particularly important in the development of virtual environments.

2.4.2 VR Related Technologies

There are several technologies that are often used for VR [14]:

- Displays: immerse the user in the virtual world and block out the real world.
- Graphics rendering engine systems: generate streams of images at least at 20 to 30

frames per second.

- Tracking systems: continually monitor the position and orientation of the user's head and limbs.

- Database systems: construct and maintain detailed and realistic models of the virtual world.

The size of the display matters for the user to have immersive experiences in the virtual world. Various formats of displays have been developed for VR such as CAVE-like (Cave Automatic Virtual Environment) surround projectors, head-mounted displays (HMDs), panoramic projectors, and workbench projectors. Graphics rendering engines have constantly improved in the last few years and will do so in the near future. Since VR requires the real-time rendering of the models with a large number of polygons, powerful and fast rendering engines are always in demand. There are various tracking systems that use different technologies: mechanical, optical, ultrasonic, and magnetic [117]. Two important parameters related to tracking systems are latency and the update rate. If these two parameters are too high, interaction and navigation in VR would noticeably be slow and not be realistic.

There are a few additional technologies that are important but not essential:

- Sound systems: synthesized sound such as directional sound and simulated sound fields.

- Haptic systems: synthesized forces and other haptic sensations.

- Input devices: devices by which the user can interact with virtual objects.

- Interaction techniques: techniques that enable the user to interact with the physical world.

VR techniques are extended to two emerging technologies: techniques of augmented reality (AR) and mixed reality (MR). In the AR, 3D virtual objects are integrated into a 3D real environment in real time [6]. Unlike VR which does not allow a user to see the real world around him or her, AR lets the user to see the real world, with virtual objects superimposed upon or composited with the real world (see-through). In this way, AR enhances the user's perception of and interaction with the real world and provides information that the user usually cannot detect with his or her own senses. This function of AR helps the user to perform real-world tasks better. The converse concept of AR is augmented virtuality (AV) which enhances the virtual environment with information from the real world. MR covers a continuum from AR to AV [75, 110]. Thus, a MR environment is one in which real world and virtual world objects are presented at the same time within a single display. In the MR environment, virtual objects created by VR techniques and real environment settings are blended in the user's experience.

2.4.3 Uses of VR

As the technologies of hardware and software are being advanced, VR systems are being widely used for many different purposes. The followings are a few examples that use VR:

VR Training

VR has been used for various training purposes. Flight simulators are well known VR systems. Nowadays, the physical setup of these simulators exactly models the real airplanes such as the interior of the cockpit and all the displays [14]. They also faithfully reflect the dynamics and simulated motions of the airplanes with visual and sound effects. Thus, pilot trainees feel as if they were steering real airplanes in the real environment. Another area where VR is heavily used for a training purpose is medicine. Surgical training using VR is popular and it is reported that VR training has reduced medical errors [36]. Military training is another example of how VR can be utilized avoiding real dangers. Combat training and emergency rescue mission training have also been simulated using VR [69].

Industrial VR

VR has been used in industry to visualize products and prototypes or to test (simulate) them. For example, new architectural design or spatial arrangement of buildings can be effectively tested using VR (architectural walk-through) [14]. Newly designed cars, airplanes, and ships or the mechanical parts of them can be evaluated using VR in a cost-effective way. VR is applied to the design and manufacturing processes of many products [77].

VR Entertainment

Early attempt to introduce immersive VR entertainment systems into individual homes was not so successful due to the high cost. However, as low-cost VR devices and supporting software are being developed, the VR in entertainment area is becoming more promising. On the other hand, VR systems have been installed for arcade games and theme parks, providing a more thrilling experience to the users [76].

VR Therapy

VR therapy has become popular among therapists to use it for their patients. In the highly scalable, controllable VR environment, patients are exposed to simulated stimuli for therapeutic purposes. VR rehabilitation has been successful in many different areas: cognitive rehabilitation and anxiety treatment (treatment for acrophobia, flying, driving, school phobia, and so on) [93]. VR has also been used to distract patients so that they do not focus on their pain while they were being treated [125]. Successful cases have been reported in VR delivering exposure therapy for the patients with "Post Traumatic Stress Disorder" (PTSD) such as some of Iraq War veterans [91]. As low-cost, portable VR devices (like a portable HMD) are being developed, therapists can visit and treat their patients at home using VR.

VR Research Tools

Some researchers use VR systems as their research tools. The advantages of using virtual environments (VE's) include: the cost of building VE's is much less than for physical environments; it is much easier to control and modify situations in VE's than in physical environments; by using VE's, we can avoid any real danger, harm, or risk but still achieve dynamics of real-world environments; it is also easy to control all the experimental variables and record the changes of their values. In natural or applied science research, researchers use VR to visualize their research data [24]. VR has also been used for various kinds of social science research experiments, including psychological and educational research experiments [71, 113].

2.4.4 Issues for VR

Some of the issues involved in using VR are: "How much immersion is needed to experience presence in a VR environment?" and "How much does it cost to build such VR environment?" In order to build a virtual environment immersive enough to experience "presence," many different components of immersion are required such as field of veiw (FOV), field of regard (FOR), frames per second (FPS), stereoscopy, and so on as noted above. But depending on the purpose of the VR system, all the components are not necessarily needed [9]. Maybe what is needed for users to experience good presence are just some of the components like a display and FOV when their size and angle are properly selected and set up. Some studies show that realistic auditory and haptic stimuli might be more important than realistic visuals depending on the purpose of the VR [14]. If all the components are not needed, the cost of building a VR environment can be reduced and uses of VR can be more practical in various ways.

Another issue is "VR sickness" caused by prolonged immersion in computer-generated worlds [93]. Some people who were exposed to the virtual environment for a long time (30 minutes or more) reported the symptoms of vertigo, motion sickness, flashbacks, spontaneous seizures, nervousness, and antisocial behaviour. Some of the cases are caused by low frame rate (less than 15 FPS). However, as graphics technology is being advanced, the problem of frame rate can easily be solved. Reducing the exposure time to the VR environment can overcome some or all of the symptoms.

2.5 Pedestrian Simulation

Research on modeling and simulating pedestrians has been a constant interest in the communities of computer animation, artificial intelligence, physics, transportation science, and other interdisciplinary areas. The reason that many communities from different disciplines are interested in pedestrian research is that it addresses many challenging topics such as natural movement, navigation, and the flow of pedestrians in a certain environmental configuration. In this section, we survey various pedestrian research studies and their trends.

2.5.1 Pedestrian Research in Computer Animation

Many researchers in the computer animation community are interested in developing the natural movement of pedestrians in a 3D virtual environment. Some researchers concentrate on the modeling of the natural walking movement of a single pedestrian (or human) whereas others have more focus on the movement of multiple pedestrians. For example, Bruderlin and Calvert developed an animation of the single pedestrian's walking using the combination of the techniques of both goal-directed and dynamic animation [15]. Goal-directed animation is animation in which the users control a high-level task represented as parameterized goals. The low-level movement such as a joint rotation and the global coordination of a motion is done by the computer with the given knowledge or rules. Dynamic animation applies laws of physics to simulate natural forces and torques in the movement of objects. By combining both techniques, they could produce more realistic walking motion with relatively simple specification. Kuffner devised a technique for an animated human character to navigate from an initial location to a goal location in interactive virtual environments without collision [65, 66]. He used many techniques originally developed for autonomous mobile robots such as motion planning, control, and sensing. Some researchers tried to incorporate emotion into human character animation such as sad walking [2, 3]

Seminal work was done by Reynolds on the animation of a group of agents [88]. Instead of defining all the paths of the characters, he specified a few simple behavioural rules for the characters to follow. The resulting animation showed simulated flocking behaviours which look realistic and natural. This idea is applied to the simulation of multiple pedestrians [32]. Magnenat-Thalmann and Thalmann have had an extensive research on virtual humans and their behaviours for the last 30 years [73]. They have been trying to create believable virtual humans with realistic appearance, motion, and behaviours. Thalmann and his colleagues developed realistic crowd (multiple pedestrians) simulations [87]. In their simulation system, the users can interact with the agents of the crowd in real time. The agents show "Flee" behaviour in the occurrence of emergency situations such as a fire or a gas leak [115].

2.5.2 Pedestrian Research in Artificial Intelligence

Some of the pedestrian research studies done in the artificial intelligence (AI) community utilize AI techniques to generate an interesting and realistic behaviour of pedestrian agents. Silverman and his colleagues focused on realistic agent behaviour rather than appealing animation [99]. Developing a comprehensive agent architecture with the various elements of the cognitive appraiser, utility generators (OCC model [81]), concern ontologies, and Markov chains, they could demonstrate the emergent behaviour of the people who protest.

In modeling a pedestrian as an agent, Donaldson and his colleagues used the OCC model to show how emotions influence the behaviour of an intelligent pathfinding agent [27]. By combining a variation of the OCC model and a pathfinding algorithm, they could generate interesting behaviours of the agent.

2.5.3 Pedestrian Research based on Physics and Social Forces

The interest in pedestrian simulation in the physics community may be caused by the fact that each pedestrian can be considered as an individual element and that certain laws like laws of physics can be applied to the interactions among the elements. Helbing and Molnár used "social forces" similar to equations of motion in Newtonian mechanics for their pedestrian model [49]. Yu and his colleagues developed a centrifugal force model for pedestrian dynamics [132]. In recent years, there has been much research on pedestrian simulations using cellular automata (CA) [61, 122, 133]. In the CA, simple local rules describing the behaviour of each automaton can produce an approximation of actual human behaviour [121]. Repeat interactions among grids of cells following the microsimulation rule set generate the emergent group behaviour.

2.5.4 Pedestrian Research in Other Areas

Pedestrian research in the community of transportation science has practical purposes such as proposing a policy on the design of pedestrian facilities before their implementation [112] or assessing the design of walking infrastructure [53]. Since pedestrian traffic is almost always involved with vehicular traffic in the urban environment, there have been studies on the relationships between these two focuses of traffic [108, 58]. There has also been research on modeling pedestrian walking speeds on sidewalks for urban planning [1]. Another study about pedestrian flow at bottlenecks has been done with real human subjects at bottleneck that was artificially created [26].

Chapter 3

Modeling a Pedestrian

In this chapter, the agent model of a pedestrian that incorporates the ideas of CPTED and fear of crime is described.

3.1 Assumption and Scope

From the beginning of this research, it was planned to test the pedestrian model against real human behaviour. Thus, it was decided to make the model simple enough that it could be validated with experiments with human subjects. If a complicated internal architecture of an agent such as an emotion system with all different emotions were developed, it would be very difficult to test with real human subjects. We focus on one kind of emotion, fear, in this research. There are also many different kinds of fear: fear of height, fear of water and so on, but we are interested in fear of crime caused by features of the urban environment such as narrow passageways without escape routes, hidden spaces created by corners, garbage dumpsters, and threatening individuals on the street.

A pedestrian is defined as a walker or as a person who goes or travels on foot. Our initial assumption is that the pedestrian who navigates the urban environment has a mental map of the areas to be navigated and has a specific personality such as bold, normal or fearful. The pedestrian navigates from his/her starting position to goal position. His/her logical choice of the path would be the shortest one. As the pedestrian navigates, he/she constantly scans the surroundings. If the pedestrian has to make a choice of routes, one of which seems more dangerous or risky than the other(s), then he/she can choose the safer one or not. This process is repeated until he/she reaches the goal position. Based on these

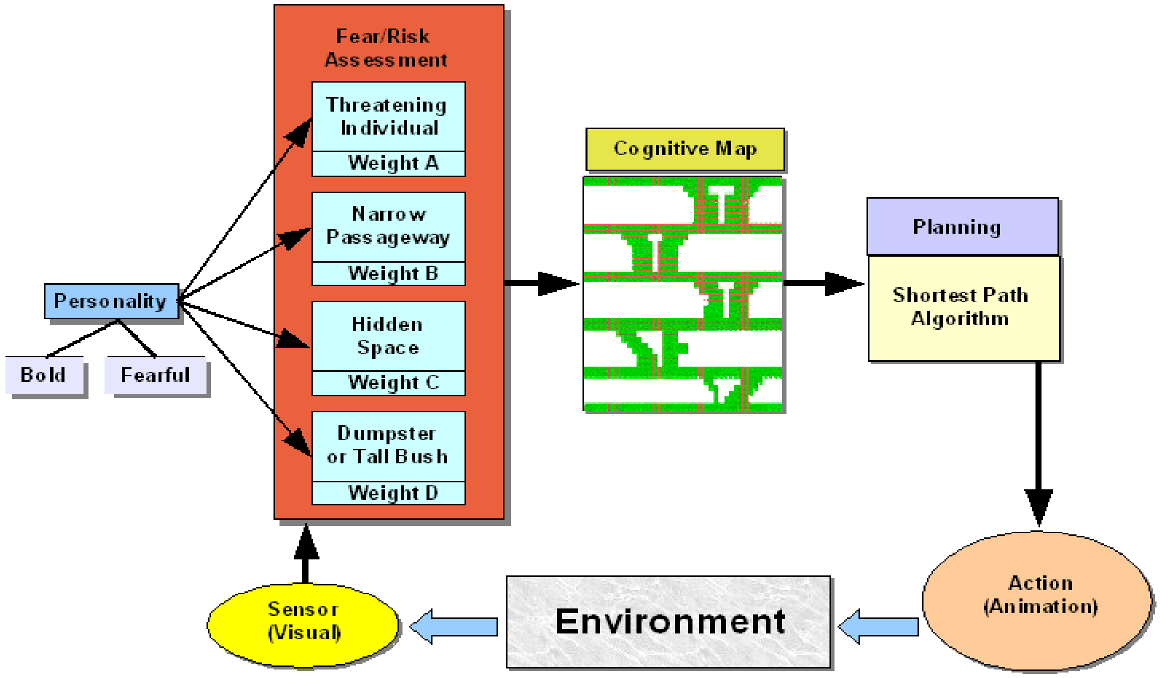


Figure 3.1: Pedestrian model architecture

assumptions we have developed a computational model of a pedestrian. At this point, we use a model of a single pedestrian, not multiple pedestrians, as that can affect the fear level of each individual. The model of the pedestrian uses the visual sense to perceive the surrounding environment. A more sophisticated model would use additional senses such as audition and olfaction to influence the pedestrian's choice of routes. But for most people, the visual sense is the primary one used to sense their surroundings.

3.2 Pedestrian Model Architecture

Our agent model of a pedestrian consists of several components: sensors, personality, fear/risk assessment, cognitive map, planning, and action as shown in Figure 3.1. Each component has particular tasks and works with other components for the agent to make a choice of routes until he or she reaches his or her goal.

Sensors

As noted, at this stage of our research, we only use the visual sense to perceive the agent's surrounding environment. Figure 3.2 shows the pedestrian agent's eye rays that are used for many different purposes. The long eye ray can detect far off objects whereas short, side eye rays detect narrow passageways and hidden spaces.

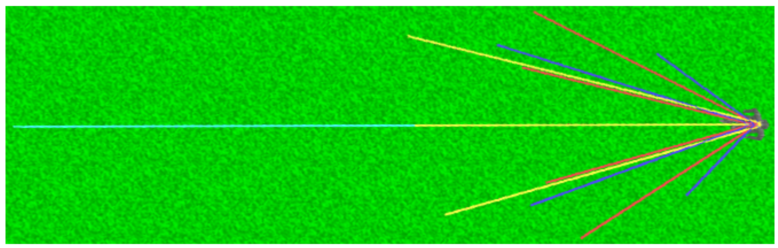


Figure 3.2: Pedestrian's simulated visual sense

Using the eye rays, the agent not only detects objects, but also distinguishes between different objects. For example, the agent can distinguish among building structures, bushes, and human individuals. With the visual sense the agent can also determine whether the walkways are narrow or wide. This is done using the visual system which has a field-of-view angle of 60 degrees. Another thing the agent can do is recognize a hidden space. By comparing two different lines of sight on the same side, the agent can figure out the existence of hidden spaces (Figure 3.3).

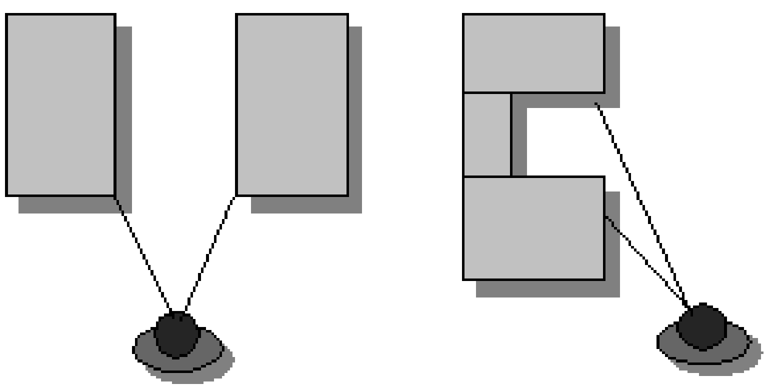


Figure 3.3: Sensing width and a hidden space

Personality

Information about the surrounding environment is interpreted in the context of the personality and emotional makeup of the individual. Since we focus on one particular emotion, fear, personality simply differentiates fear weight values. Fear weight values are the values of different environmental features that show how much pedestrians are fearful about those features. We set three different personalities: Bold, Normal, and Fearful. The Bold personality increases the fear weight values, the Fearful personality decreases it, and the Normal one is in-between.

Some might argue with the choice of only three different personalities. It is computationally possible to set a continuous function for them instead of three discrete levels. However, we plan to test our model against real human subjects and our ability to distinguish fear levels is limited. It would be very difficult to determine a subject's personality, whether he/she is "very" bold or "slightly" fearful. A criminologist whom we consulted even recommended setting only two personalities: fearful or not fearful for the purpose of testing the model against real pedestrians. We take the behavioural approach to measure fear levels: if he/she avoids a certain feature of the environment, we believe that he/she might be fearful of that feature. Otherwise, he/she is bold about the feature. We confirm this assumption through post experimental interviews with the human subjects. In general, the bold personality of our pedestrian agent lowers the fear weight values of all testing environmental features whereas the fearful personality raises the values even though the amount of the value increased/decreased by the particular personality might be different for each environmental feature.

3.2.1 Fear/Risk Assessment

The fear/risk assessment component is the component that assesses the fear levels of the environmental features that a pedestrian senses. It has a list of the environmental features with their fear weight values. Depending on the agent's personality, the fear weight values can be either higher, lower, or in-between. Different environmental features have different fear weight values. For example, as noted earlier, social incivilities seems to generate more fear than physical incivilities. Thus, we assigned higher fear weight values to threatening individuals than other environmental features such as narrow passageways or hidden spaces. The fear/risk assessment component finds the environmental feature in the list, if there is any, based on the information given by the sensor component at each cycle. Then it delivers that information along with its fear weight value to the cognitive map component.

3.2.2 Cognitive Map

The cognitive map component contains a mental map of the environment where the pedestrian agent navigates. At the beginning of the navigation, the map only has the information about the route configuration and fixed buildings, not movable objects such as dumpsters or individuals. As the agent navigates, the sensor detects the objects and environmental features. This information is interpreted by the fear/risk assessment component and given to the cognitive map component along with any fear weight values. Based on this information, the mental map is updated.

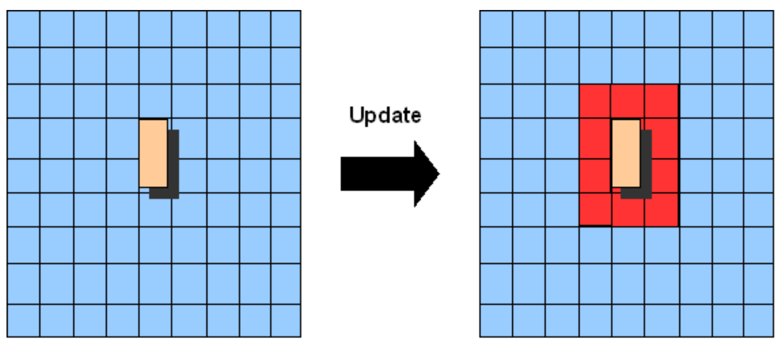


Figure 3.4: Mental map updated with a dumpster

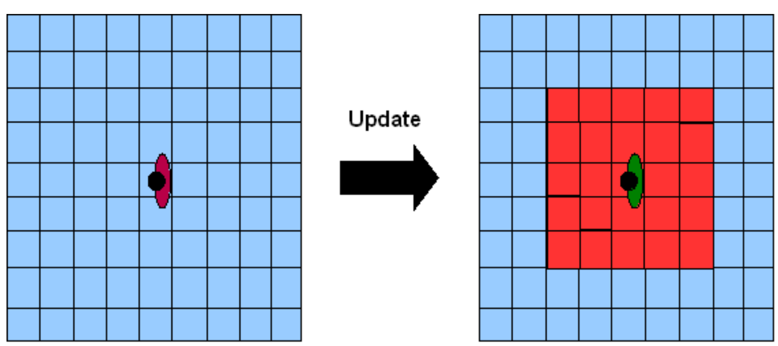


Figure 3.5: Mental map updated with a threatening individual

As we see in Figures 3.4 and 3.5, the surrounding cells of the detected objects or environmental features would have higher cost values after the update for the shortest path calculation. As a result, the pedestrian agent avoids such objects and environmental features. It is like creating a repulsive potential field around them. However, the range that covers cells of higher cost values depends on the fear weight values. If an object or an environmental feature has a higher fear weight value like a threatening individual, the range covers more cells around it whereas an object or an environmental feature with a lower fear weight value like a dumpster has a smaller range. The resulting behaviour would be that the pedestrian agent keeps a longer distance with a threatening individual than a dumpster while he/she avoids them.

3.2.3 Planning

The planning component calculates the shortest path from the pedestrian agent's current position to the goal position based on the mental map created by the cognitive map component. If there is no update on the map, the component does not calculate a new shortest path.

3.2.4 Action

The action component moves the pedestrian agent one cell per cycle along the path that has been planned and runs a pre-made walking animation sequence.

3.3 Animation

Since our pedestrian model is simulated as a 3D human character in the 3D virtual environment, animating the natural walking of the character is important for better visualization. We used a simple female 3D character for our pedestrian model. To generate a natural walking animation with the character, we used a program called Character Shop, which comes with over 80 pre-made animations. We had to simply rig the skeleton to the model and apply the walking animation to it. The walking animation produced is good enough for our simulation. However, the limitation of the program is that it does not provide any animations that show emotions. It is obvious that a fearful person's walking motion would be different from that of a bold person. In fact, generating emotional animation is a whole other research topic [2]. We will consider this aspect of our character animation for our future research. At this point, our pedestrian model shows her emotion (fear) by her choice of routes.

3.4 Implementation

In order to simulate our pedestrian model in a 3D virtual environment, we had to find a good programming tool and a 3D game/animation engine. There are many well known game engines such as Unreal and Torque. But there is a relatively long learning curve to become familiar with all of their application programming interfaces (APIs). We tried to find a simple and straightforward programming tool that also easily supports 3D animations. After trying several tools, we eventually chose Darkbasic Professional, a game development package. It uses a BASIC-like language and incorporates the features of Microsoft DirectX 9 technology. Using this tool, our pedestrian model has been programmed along with its simulated urban environment.

Since Darkbasic Professional comes with collision detection commands and add-ons, it was not difficult to implement the sensor component. For the planning component we simply used the A* algorithm [45]. The A* algorithm is a graph-search algorithm that finds a shortest path between the start position and the goal position. The algorithm uses the Manhattan metric as the heuristic, which thus guarantees that A* will always return the shortest possible path[1] even though the algorithm can consume considerable amounts of time and memory. The A* algorithm turns out to be a choice of algorithms in many video games. We made the simulated urban environment grid-based. For each iteration, the agent moves from one grid cell to another. Figure 3.6 is the main algorithm (in pseudo code) that is used in the pedestrian model.

The integral pedestrian simulation system (PEDSIM) allows different spatial environments to be created with buildings, dumpsters, and threatening individuals and tested with pedestrians with different fear thresholds such as bold, normal, or fearful. The map that is created can be saved and the speed of the simulation can be varied. The path can be marked by arrows to visualize it. We can make the pedestrian's lines of the sight either visible or invisible.

[1] A* will find optimal paths with any heuristic that meets certain mathematical constraints.

```
Data: Start-position, Goal-position
Result: Reaching Goal-position or no path
initialization;
while current position is not Goal-position do
    find the shortest path to Goal-position;
    if the path exists then
        while current position is not Goal-position do
            find a target cell to move to;
            look around;
            if found something then
                /* something can be narrow route, hidden space, street
                   person, or dumpster.                                  */
                if no fear then
                    move to the target cell;
                else
                    Start-position ← current position;
                    change the cost value of the cells around something;
                    exit /* exit the inner while loop.                   */
                end
            else
                move to the target cell;
            end
        end
    else
        there is no path to Goal-position
    end
end
```

Figure 3.6: Main algorithm for the pedestrian model.

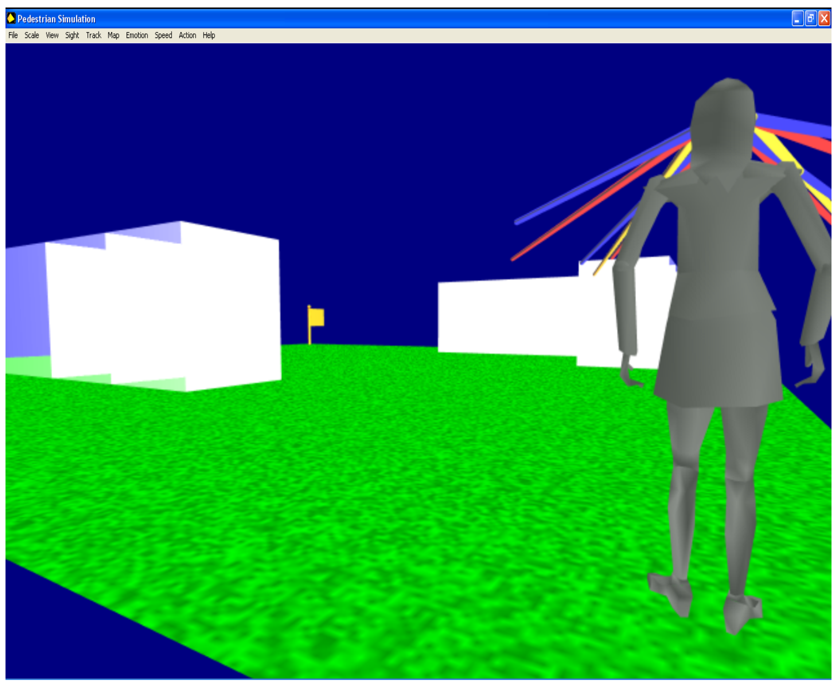


Figure 3.7: Pedestrian simulation system(PEDSIM)

Chapter 4

Simulation of the Pedestrian Model

In this chapter, we describe our simulation experiments with the pedestrian model and their results. The simulated urban environment of Simulation I resembles a well-known fear-generating area (the Downtown Eastside of Vancouver) and that of Simulation II is artificially made with the intention of testing particular environmental features.

4.1 Simulation Experiments I

We created a simulated urban environment in the PEDSIM that reflected a map of the Downtown Eastside of Vancouver (a well-known fear-generating area) (Figure 4.1). Then we simulated our agent model of a pedestrian in PEDSIM with different personalities. We created a scenario in which a traveler visits downtown Vancouver and wants to walk from Gastown to Chinatown. He or she has a map but does not know whether or not threatening individuals are along the way.

4.1.1 Simulation using the “Bold” Personality

The traveler with the ”Bold” personality followed the shortest path except avoiding collisions with threatening individuals (Figure 4.2). He or she did not mind passing the hidden space, narrow walkways, and threatening individuals, showing a bold behaviour.

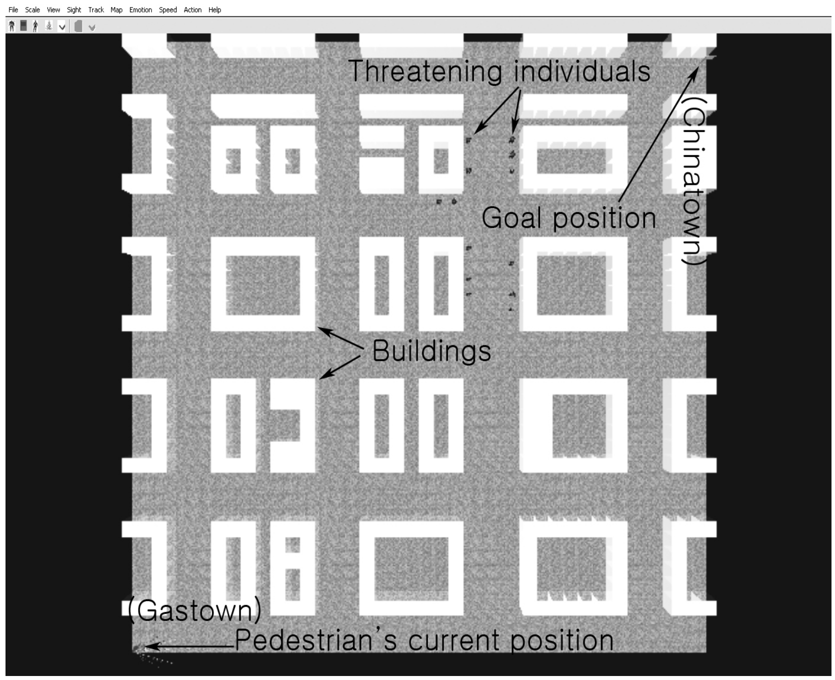


Figure 4.1: Simulated urban environment I in PEDSIM

4.1.2 Simulation using the "Normal" Personality

The traveler with the "Normal" personality walked through a narrow alley but did not go through the street where there were multiple threatening individuals (Figure 4.3). He or she was more afraid of the threatening individuals than fearful environmental features.

4.1.3 Simulation using the "Fearful" Personality

The traveler with the "Fearful" personality neither went through narrow walkways nor the streets with multiple threatening individuals (Figure 4.4). He or she chose the safest path to reach the destination.

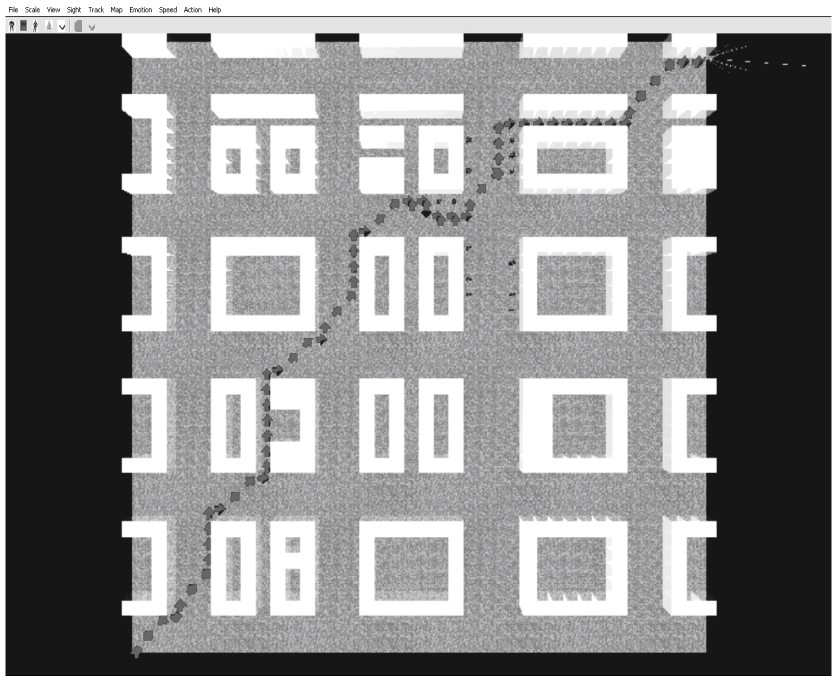


Figure 4.2: Simulation I using the “Bold” personality

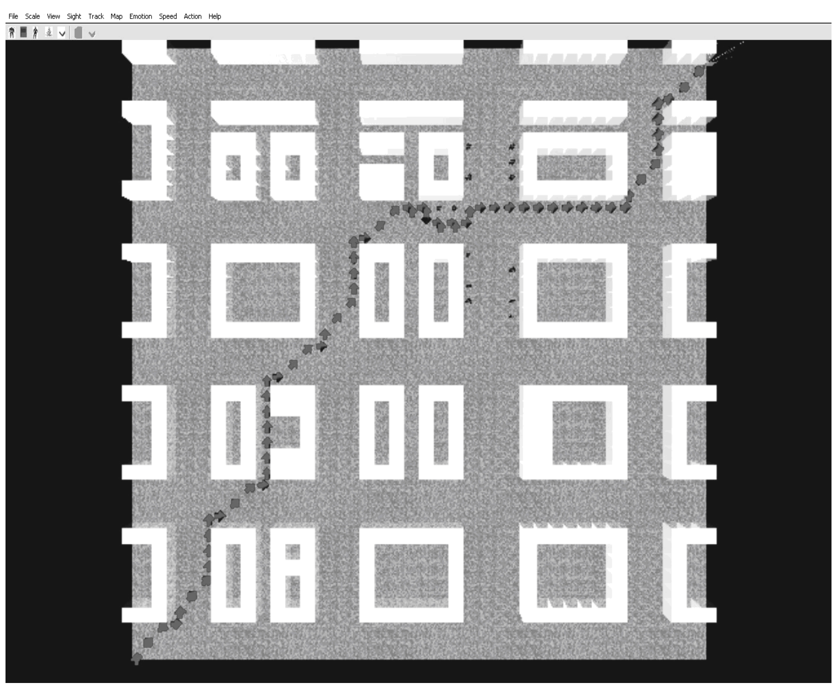


Figure 4.3: Simulation I using the “Normal” personality

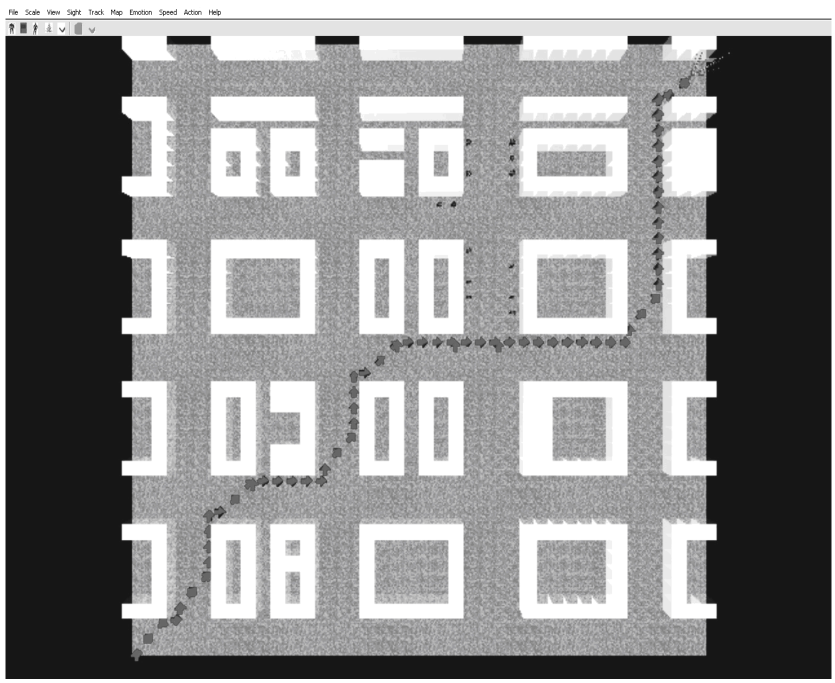


Figure 4.4: Simulation I using the “Fearful” personality

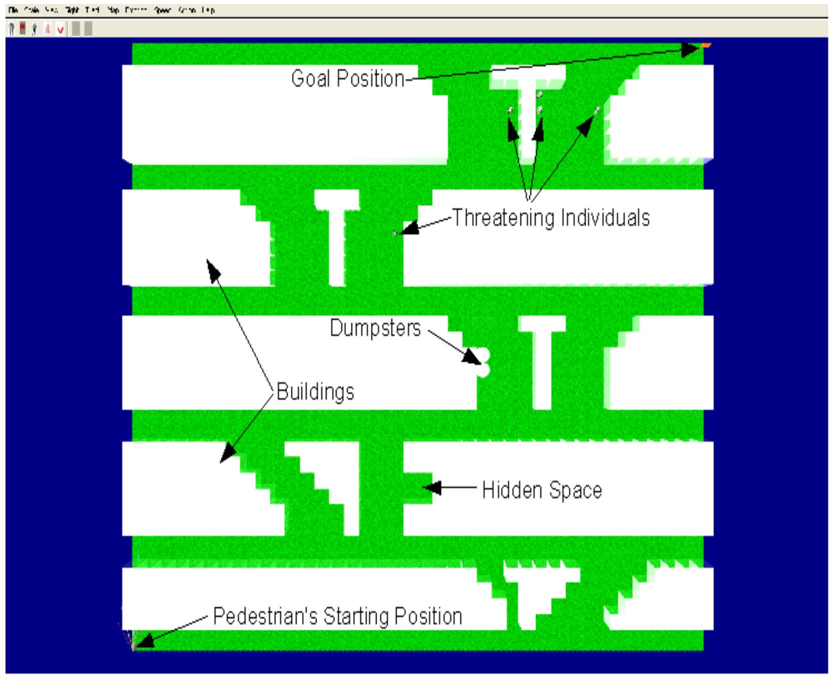


Figure 4.5: Simulated urban environment II in PEDSIM

4.2 Simulation Experiments II

For the second simulation experiments, we specifically set up five decision points on the way to the destination (goal position): Narrow/wide passageways, streets with/without hidden space, streets with/without dumpsters, streets with/without a threatening individual, and streets with a single threatening individual or multiple threatening individuals. These environmental features were chosen based on the literature review [10, 120, 35, 68, 86, 83, 12, 94, 101, 50] and the fact that these features were frequently found in the areas that we were interested in. The last feature was set up to investigate the relationship between the number of threatening individuals and fear of crime. The scenario that we were assuming in the experiments was that a traveler visits this area and walks from the starting position to the goal position. He or she has a map with all the streets and buildings but does not know whether or not dumpsters and threatening individuals are along the way (Figure 4.5).

4.2.1 Simulation using the "Bold" Personality

The first simulation was done with the "Bold" personality. The pedestrian agent chose the narrow passageway, the street with hidden space, the street with dumpsters, the street with a threatening individual, and the street with multiple threatening individuals (Figure 4.6). Basically, he or she followed the shortest path to the destination, which represents a behaviour not affected by any possible fear-generating features of the environment.

4.2.2 Simulation using the "Fearful" Personality

The second simulation was run using the "Fearful personality. Compared to Figure4.6, Figure 4.7 shows how the pedestrian agent dynamically changes his or her routes affected by the fear-generating features of the environment. He or she tried to go into the narrow passageway since it was the shortest path. But he or she suddenly changed his or her route and chose the wide passageway. Even though he or she chose the street with hidden space, he or she went around the hidden space. On the street with dumpsters, he or she was going halfway through. But then he or she turned around and took the other way without dumpsters. He or she simply avoided the street with a threatening individual. At the final decision point, the agent saw the single threatening individual and decided to take the other street. But he or she found more threatening individuals on the other street and came back and passed by the single threatening individual. This agent behaviour reflects the behaviour affected by the fear of crime in the urban environment, corresponding with the findings of social science research.

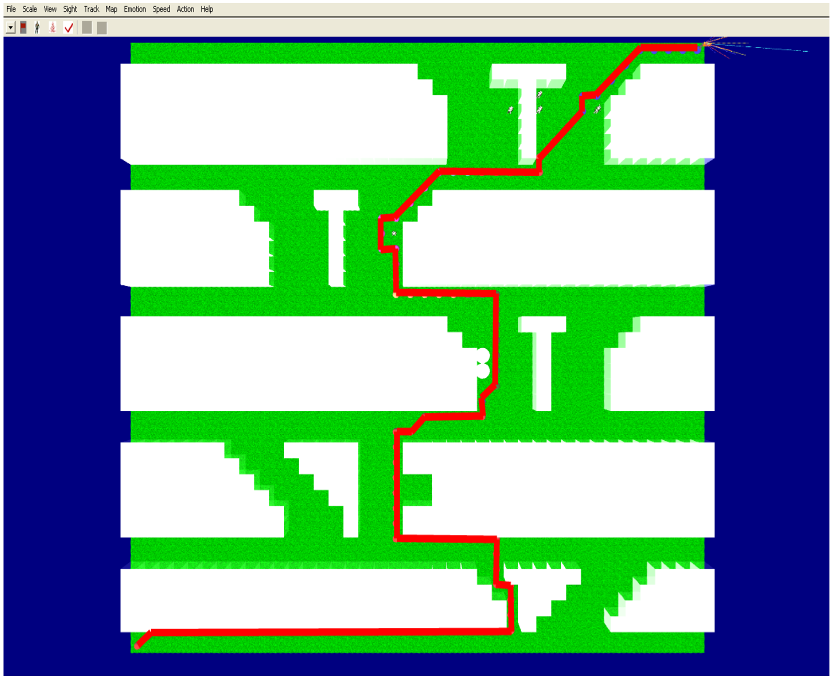


Figure 4.6: Simulation II using the “Bold” personality

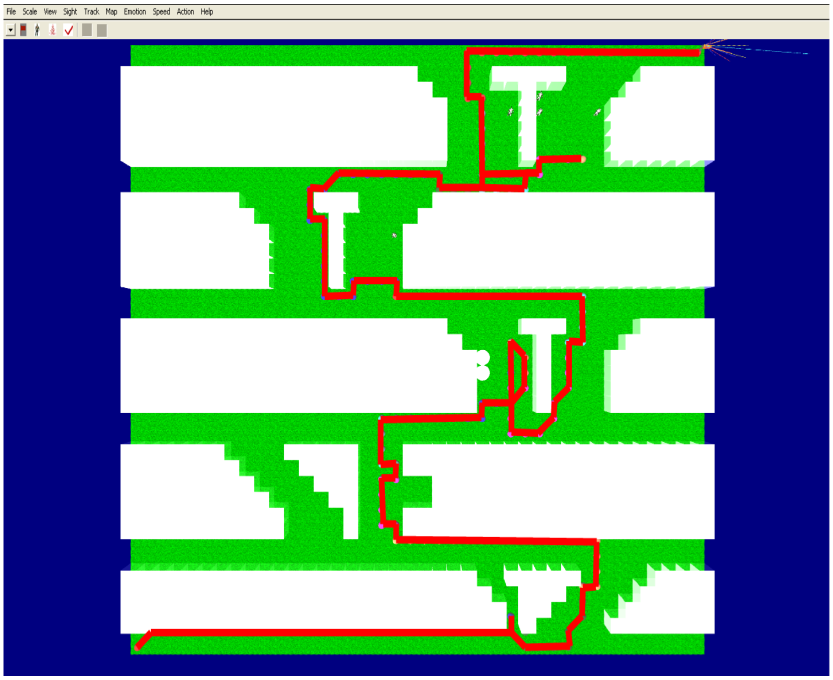


Figure 4.7: Simulation II using the “Fearful” personality

Chapter 5

Experimental Methodology for Model Validation

In this chapter, the validation of the pedestrian model and the resolution of outstanding issues are discussed. The experimental methodology used for this research is also described.

5.1 Validation of the Model

Our pedestrian model was tested in a simulated environment and its results reflect the findings of social science research. However, it does not necessarily mean that our model has been validated. In order to validate the model, we have to show that the pedestrian model behaves as real people do in real-world environment. First we tried to find existing research results that could be compared with our model. But it was difficult to find applicable cases. Even though there are many social science studies regarding how people feel about certain features of the environment, we could not find any cases that show the way people dynamically change their routes influenced by the fearful features of the environment. Then we decided to observe real people in several fear-generating areas in the lower mainland of British Columbia. Three different areas were chosen for observation: the Guildford shopping mall area in Surrey, the area at the intersection of Kingsway and Edmonds Street in Burnaby, the area of the Commercial skytrain station in Vancouver, and the area of the Downtown Eastside in Vancouver. However, there were several issues and limitations as we tried to observe real people to validate our model:

- It is difficult to control all the experimental variables. For example, when we choose a certain feature of the environment such as a hidden space or a narrow passageway as our dependent variable, it is hard to keep them pure because of constant interfering factors such as other pedestrians, cars, changing light, sound, and so on.
- It is not easy to find out where each pedestrian is going. According to the nature of our model, we have to know the starting place and destination of a pedestrian. But it is hard to trace each pedestrian to know his or her destination.
- It is not easy to eliminate or minimize the influence of the observer in the open space.
- It is difficult to find an area that has all the fearful environmental features that we would like to test.
- Even though we can discover a person's path from the starting place to the destination, it is difficult to know why they have chosen particular path.
- There are ethical issues in observing people in a fear-generating area.

It was suggested that we could observe pedestrians from the top of a building (maybe using a time-lapse video camera) to observe their behaviour influenced by the fearful features of the environment. However, it could take a long time to collect and analyze useful data as we saw with William Whyte's research (which took 16 years!) [124].

Another choice that we considered was placing human subjects in a real-world environment and asking them to navigate from the starting place to the destination. In this way, we can overcome some of the issues and limitations that we had with the simple observation such as not knowing pedestrians' starting place and destination and reasons of their choices. However, we still have the rest of the issues such as interfering factors of the environment. In addition, there are ethical issues related to the risk and danger involved in this kind of experiment. In some fear of crime research studies, human subjects visited various campus sites and reported their feelings about the sites [79]. But for the safety of the subjects, the researcher and a police/escort agency followed them and oversaw the activity of the subjects. If we move from a university campus which is relatively safe to a well-known fear-generating area where there are obvious, practical dangers and risks, ethical issues become a more serious matter.

Finally, we decided to use a virtual environment (VE) for our experiments with human subjects to validate our model. As we mentioned in our background chapter, VR systems have been used as research tools in various academic disciplines. In the subsequent section, we discuss in detail the use of a VR environment as our research experimental tool.

5.2 Experimental Methodology

5.2.1 Using a Virtual Environment for Experiments

VR technologies have been used for many research studies. Here our interest is in the use of VE's in place of real-world, physical environments for our research study.

Benefits of Using Virtual Environments

It is often difficult to use real-world environments for experimental research with human subjects, as was noted in the previous section. However, we found that VE's could be a good alternative with the following advantages:

- It is much easier to control and modify situations in VR environments than in physical environments.
- It is easier to control experimental variables and interfering factors in VR environments than in physical environments.
- By using VR environments, we can avoid real danger, harm, or risk but still achieve dynamics of real-world environments.
- In many cases, the cost of building VR environments is much less than for physical environments.

In particular, it is beneficial to use VR environments in CPTED/fear of crime research because of the nature of the research and ethical issues involved.

Given the state of VR technologies today, visual realism is good enough for the subjects to experience presence. If we add other stimuli such as sound, we can experience even more presence.

Examples of Using Virtual Environments for CPTED/Fear of Crime Research

There have been a few studies using VE's in CPTED and fear of crime research. Cozens and his colleagues used interactive VR scenes to study fear of crime at railway stations [21]. They took photographs of several 360 degree panoramas at various points at the stations. These photographs are then stitched together to create a VR walk-through scene. Participants can virtually navigate the station environment, freely zooming in and out and panning left and right at any time during the navigation. This VR system provided a dynamic visual stimulus based on which participants' judgments and perceptions were generated. Manabu and his colleagues used VR technology to study the relationship between fear of crime and street lighting [57]. Cubukcu and Nasar used desktop VE's to simulate large-scale, outdoor, physical environments to test effects of plan layout complexity, physical differentiation, and gender on acquired spatial knowledge [25]. Even though this study was not directly related to CPTED/fear of crime research, it showed that VR technology allows researchers to control and manipulate characteristics of the physical environment.

Issues of Using Virtual Environments in Place of Physical Environments

There is an obvious difference between VE's and physical environments. There is a study that compares the subjective responses to simulated environments and real environments [8]. This study shows that even detailed computer simulations do not necessarily generate the same responses as the corresponding real environment. On the other hand, another study regarding path choices in the real environment and VE's shows that there is no statistical difference between them [134]. Here we see that depending upon the purpose of the research, it is not necessary to create a VE that perfectly resembles the corresponding real environment. Well-designed research experiments and their procedures help participants to engage in the experiments as if they were in a real environment, suspending their disbelief.

Chapter 6

Experiments and Detailed Analysis

In this chapter, we describe our experiments including the participants, experimental setting and protocol. The detailed analysis of the collected data is also explained.

6.1 Experiments

In this section, the details of our experiments are explained including the participants, experimental setting, and protocol.

6.1.1 Participants

In selecting subjects, it is ideal to have a completely random sample to ensure statistical significance. In our exploratory research, however, we chose convenience sampling to recruit our participants due to the nature of our research and the fact that we had to invite them to our laboratory. We tried to recruit people from all age groups and from the public who may or may not be SFU students. With the help of colleagues from the Institute for Canadian Urban Research Studies (ICURS), we were able to recruit many local people from the public at large who were interested in our research experiments (undergraduate/graduate students: 44%, employed: 36%, homemaker: 8%, other: 8%, self-employed: 2%, and retired: 2%). Some of undergraduate students came from a class of an introductory criminology course. We do not think these students were biased because we carefully designed the experiments to not reveal the purpose of the experiments at the beginning. Most of the students and the local people did not have any criminology background at all. The result was 60 participants with a range of ages even though the ratio of the age groups was not well balanced. In contrast to the fact that many fear of crime research studies simply recruit campus students, we believe our effort to recruit older people and non-students as well as young campus students provides us with more general insights into pedestrian behaviour. Figure 6.1 shows the age and gender demographics of our participants.

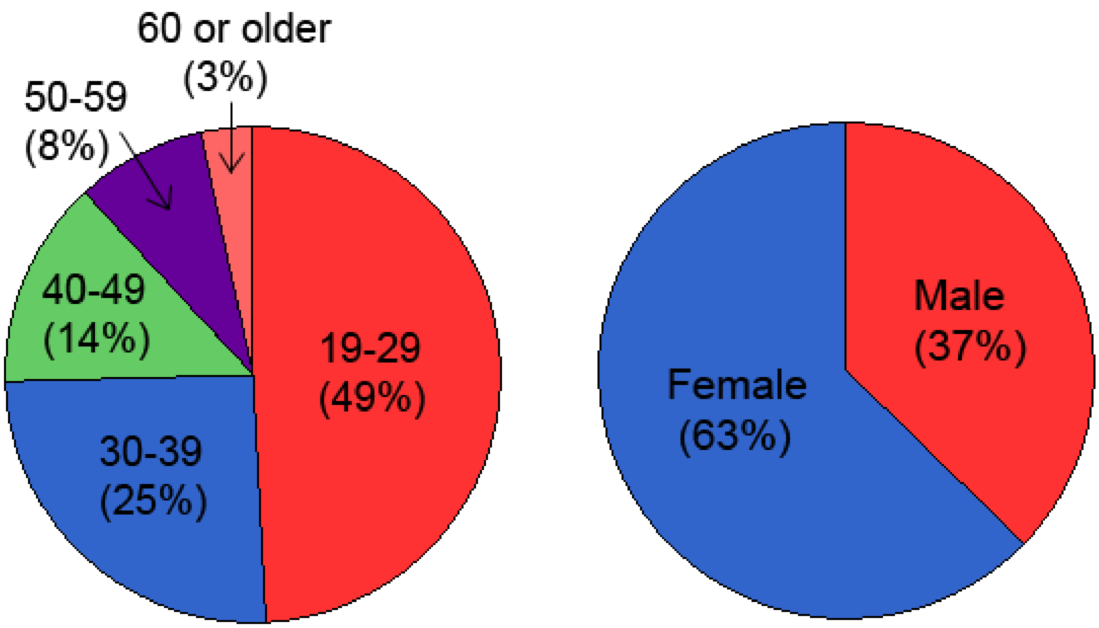


Figure 6.1: Demographic of age and gender.

6.1.2 Experimental Setting

The design of our experimental setting was arranged to help the participants experience presence during the experiments and to suspend their disbelief. Originally we wanted to make an accurate model of the Downtown Eastside of Vancouver which is a well-known fear-generating area. With a 3D modeling tool (3D Studio Max), 3D buildings and roads were created in accordance with satellite pictures and road networks from Google Map. Then photographs of the buildings in the target area were taken. It was difficult to take perfect pictures without any objects such as pedestrians, trees, cars, or street lights in front of the buildings. Different light densities due to the weather changes were another problem. We also tried to avoid shadows onto the buildings by taking photographs on a day with clouds in the sky. However, it took a lot of time to edit the photographs in Adobe Photoshop, removing unnecessary objects and shadows from the buildings and adjusting the brightness. Then these textures were mapped onto the 3D models of the buildings. As this VE was being developed, it was realized that we were reaching the limits of the performance of our computer in handling all of the model buildings with a large number of different textures. Even though one of the most powerful workstation computers (Dell Precision M90) was purchased for this project, the whole Downtown Eastside was too big to model in the VR environment. Eventually, we decided to develop a reduced model of the area with the existing textures so that the participants can still feel that they are in the Downtown Eastside area. Since we were not creating an exact model, we modified the environment with the intention of setting up the decision points to test certain environmental and other features such as narrow/wide passageways, streets with/without hidden space, streets with/without dumpsters, streets with/without a threatening individual, and streets with a single threatening individual or multiple threatening individuals. These particular features were chosen as decision points on the basis of their prominence as fear generating features in the criminology literature. The features were tested in the second simulation experiments with the pedestrian model in Chapter 4. Vehicular traffic is closely related to pedestrian traffic in the urban environment. However, due to the huge consumption of the computing power and memory and the fact that it is not directly related to the fear of crime, we postponed adding vehicular traffic to our future research. Instead, traffic background sounds were played during the experiments to add realism. A time in the middle of the day was chosen for the experiments because we thought most of pedestrians would navigate the target area during the day time rather than during the night time. We could have done experiments both in the day and at night and compared their results, however, due to the limitations of time and resource, this was reserved for our future research. Figure 6.2 shows snapshots of each decision point.

Several pilot studies were conducted to explore different experimental settings. The VisionStation by Elumens was tested with a few human subjects. Although it generated a good immersive experience, most of the subjects complained about dizziness during the navigation. Next a regular screen with a projector was tested. Subjects sat down in front of the screen and navigated the VR environment with a keyboard and a mouse. But this was not immersive enough for them to feel presence. Some people felt that they were playing a

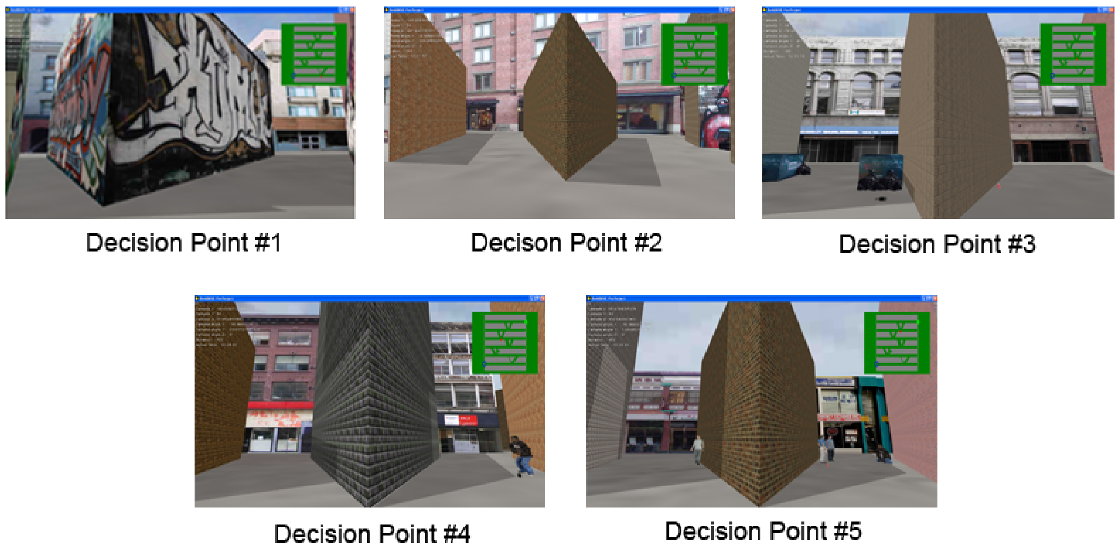


Figure 6.2: Snapshots of each decision point in the VR environment.

game. To increase the level of immersion, we set up a large screen (about 5m × 4m) so that participants could feel better presence with the big display size, the wide field of view, and the wide field of regard. To overcome subjects' feeling that they were playing a game with a keyboard and a mouse, we used a Nintendo Wii remote controller so that subjects could stand in front of the big screen and navigate the VR environment intuitively (Figure 6.3).

To help participants feel even more presence, the experimental space was surrounded with thick black curtains. Ambient background sounds of traffic were also played during the experiments. To measure participants' emotional arousal, a biofeedback device called "ProComp Infiniti" was used, which provided a measure of the galvanic skin response. This data was not used in this analysis but it was collected for future use. It was expected that we would learn the reasons for the participants' choices mostly from the post experimental interviews. We prepared a script and a protocol to ensure the consistency and validity of our experiments.

6.1.3 Experimental Protocol

The following is the protocol used for each of our research experiments.

1. Introduction and Having the Consent Form Signed (about 5 minutes)

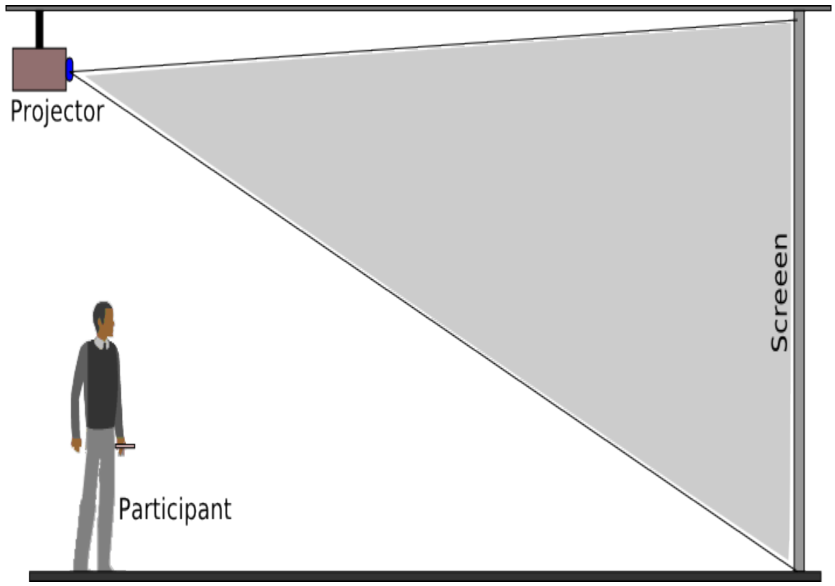


Figure 6.3: Experimental setup

Figure 6.4: A subject in the experimental space

- Introduce the participant to what he/she will do and what the experimenter will do during the experiment.
- Explain any risk of psychological stress.
- Explain that he/she has a chance to withdraw from the experiment at any time and that participation is voluntary.
- Mention that further information about the research will be given after the experiment.
- Have the participant sign the consent form if he/she decides to participate in the experiment.
- Gather demographic information such as gender, age, ethnicity, and occupation by having the participant fill out a form (see Appendix D).

2. Training (Practice) Session (about 5 - 10 minutes)

   - Put a biofeedback sensor (galvalnic skin response) on the participant.
   - The participant practices how to navigate in the virtual environment using a Wii remote controller in the virtual environment that was developed for this practice purpose. There are several mini sessions in this practice. Each session teaches essential skills to navigate in the virtual environment. If the participant successfully finishes one session, he/she can do the next session. If the participant wants, he/she can start over the whole practice session multiple times until he/she feels confident to start the real experimental session.

3. Experimental Session (about 10 - 15 minutes)

   - Explain that the participant starts to navigate from the current position to the specified destination in the virtual environment following the shortest path.
   - Explain that the participant can choose the different paths instead of the shortest path whenever he/she perceives any danger or risk from the situations they face on the way.
   - Start videotaping the participant.
   - Start to record biofeedback information.
   - Have the participant start to navigate.

- The virtual reality (VR) system starts to record x-y coordinates of the participant's position and time in the virtual environment. This information will be used to replay what they see in the virtual environment during the experiment.
- During the navigation, the participant meets several decision points where there are narrow/wide passageways, streets with/without hidden space, streets with/without dumpsters, streets with/without threatening individuals, and streets with a single threatening individual or multiple threatening individuals. The participant makes a decision which street he/she will choose to navigate.
- When the participant reaches the destination, the experimenter stops videotaping, collecting the biofeedback data, and the VR system.

4. Post-experiment Interview Session (about 10 - 15 minutes)
   - Start videotaping the participant.
   - Replay the experiment. The experimenter and the participant review the experiment session together.
   - Ask the participant his/her feelings at each decision point and reasons of their decisions.

5. Exit Questionnaire Session (about 10 minutes) (See Appendix D.)
   - The participant answers a questionnaire which asks his/her experience with the Downtown Eastside of Vancouver.
   - The Participant answers a questionnaire which asks his/her opinion about personal safety.
   - The participant answers a questionnaire which asks his/her opinion about his/her experience with the experiment.

6. Dismissal of the Participant (about 5 minutes)
   - Explain the purpose of the research and how the collected data will be used and destroyed.
   - Answer any questions that the participant asks.
   - Dismiss the participant.

6.2 Simple Analysis of Results

We conducted experiments with 60 subjects from May 7th, 2007 to July 19th, 2007. However, one of the subjects was not able to follow the instructions and thus was disqualified and not included in our analysis. Using the statistical analysis package SPSS (Version 16.0), we analyzed the data statistically.

6.2.1 Analysis of Results with All Subjects, Gender, and Age

Figures 6.5 - 6.9 show some of our experimental results. In general, the subjects chose the wide passageway (62%) more than the narrow one (38%), the street without dumpsters (68%) more than the ones with dumpsters (32%), and the street without a threatening individual (75%) more than the street with one (25%). The fact that most subjects avoided the street with a threatening individual suggests that social incivilities generate more fear than physical incivilities. This validated the assignment of higher fear weights in the model to threatening individuals and lower values to other objects and features in the model. We need to investige further to understand the results at the decision points #3 and #5.

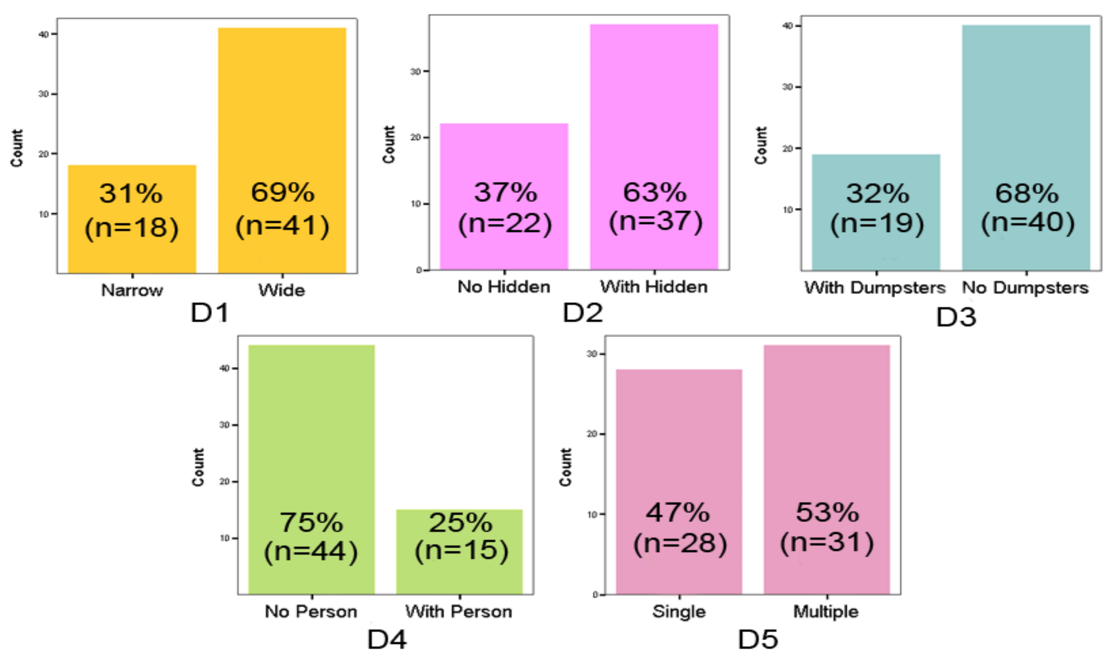


Figure 6.5: All subjects' choices at each decision point.

Figures 6.6 and 6.7 show the gender differences in the behaviours influenced by the fear of crime. The results suggest that female subjects are more fearful than male subjects. 86% of the male subjects chose the street with a hidden space whereas about half of the female subjects (51%) chose the street without a hidden space. The street with a threatening individual generates fear in both male and female subjects, but more female subjects avoid that street. The narrow passageway and the street with dumpsters generate high fear in the female subjects but less fear in the male subjects. At the decision point #5, more than half of the male subjects went to the street with multiple threatening individuals rather than the street with a single one. But for the female subjects, it was the other way around.

Figures 6.8 and 6.9 show the age differences in the choices of routes at each decision point. The age of 30 years was chosen to break the subjects between the older and the younger because it breaks them evenly in terms of number. When the age of 40 years was chosen as a break point, the ratio between the two choices at each decision point was the same or very close to that of the age of 30 years. Since the analysis with a generalized linear model does not show any statistical significance among different age groups, the age of 30 years seems a good choice as a break point. The results suggest that young subjects are as fearful as older subjects. In fact, they are more fearful about the street with a threatening individual than the older subjects. More than half of the young people preferred the street with multiple threatening individuals to the one with a single threatening individual whereas for the older subjects it was the other way around.

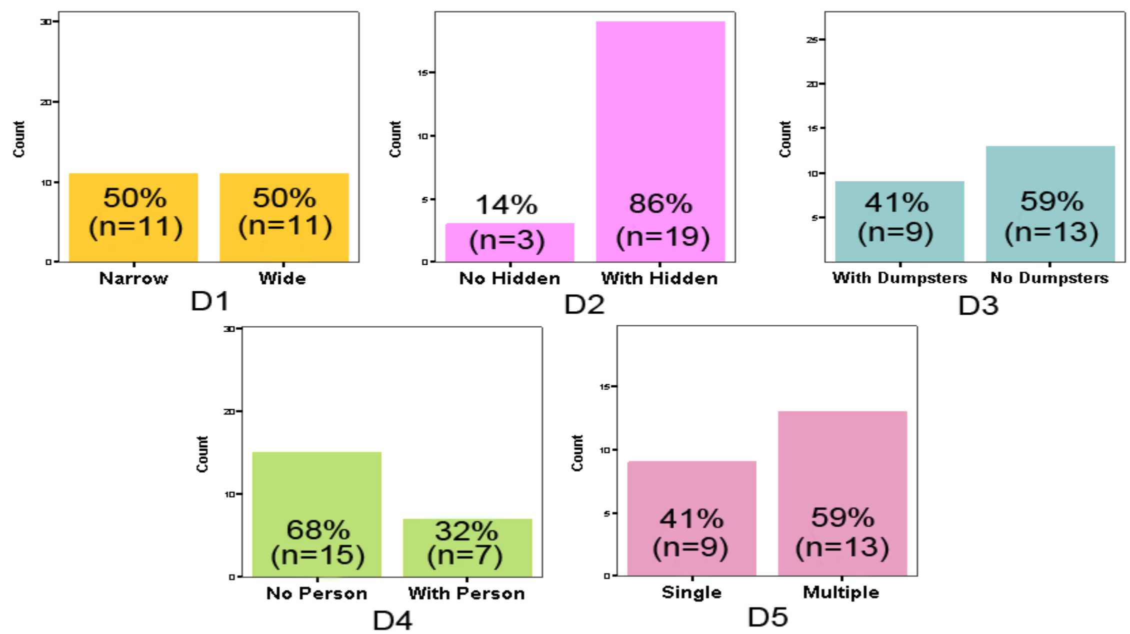


Figure 6.6: Male subjects' choices at each decision point.

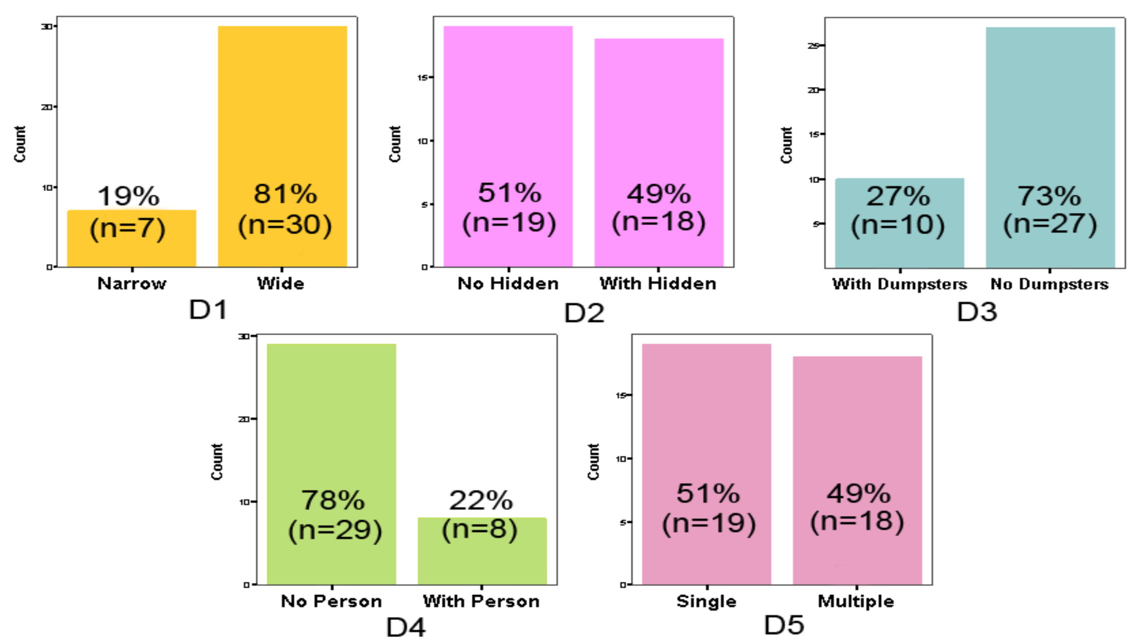


Figure 6.7: Female subjects' choices at each decision point.

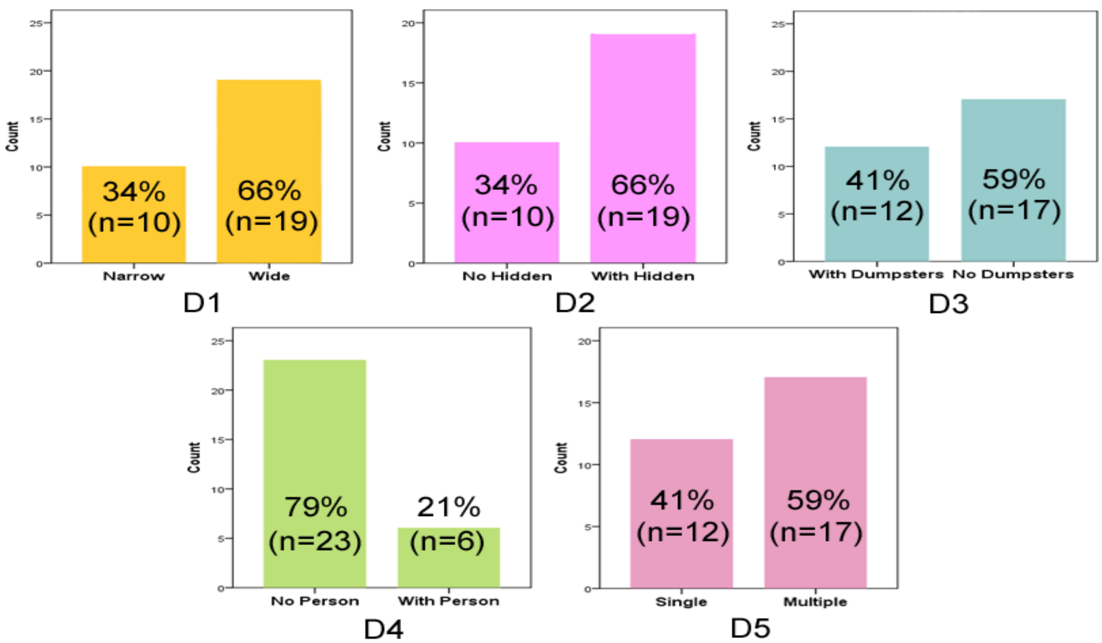


Figure 6.8: Young subjects' (under 30) choices at each decision point.

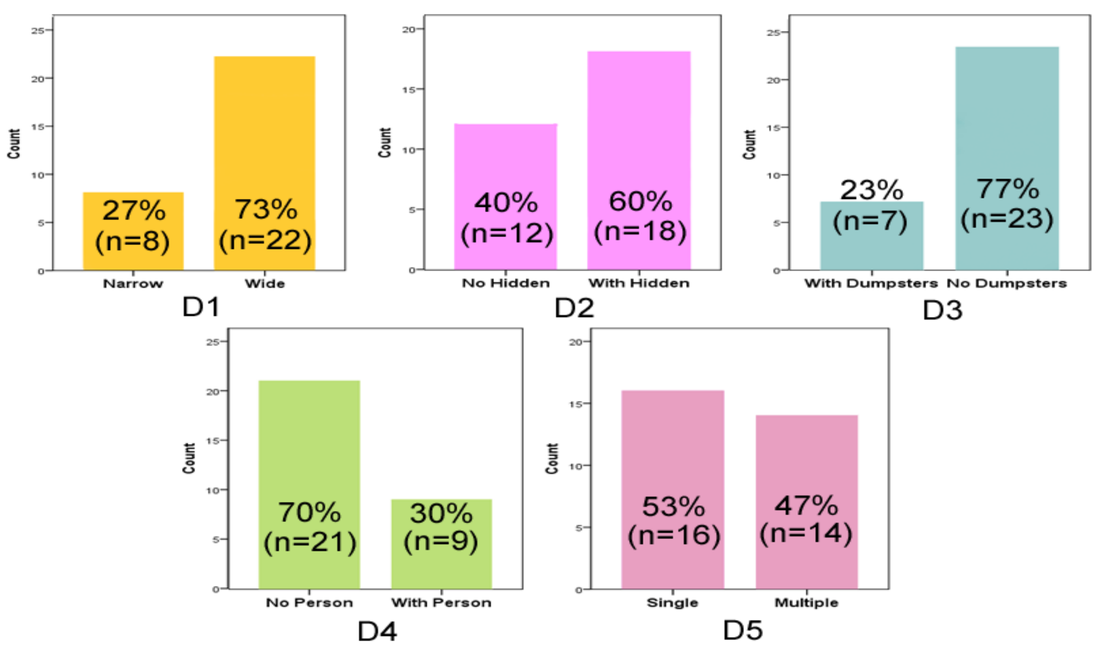


Figure 6.9: Older subjects' (30 or older) choices at each decision point.

6.2.2 Analysis of Results Based on Subjects' Judgment on the Virtual Environment

77.96% of all subjects positively answered in the exit questionnaire that they navigated the virtual urban environment as if they were navigating in the real urban environment. But 22.04% of the subjects answered that they did not navigate the VE as if they were navigating in the real urban environment. In order to find out the effect of subjective judgment of the VE on the experimental results, differences between these two groups in making choices of routes at each decision point were analyzed.

Table 6.1: Choice differences between subjects who felt real and subjects who did not.

Judgment	**DP #1**		**DP #2**		**DP #3**		**DP #4**		**DP #5**	
	Narrow	Wide	No Hidden	With Hidden	With Dump.	No Dump.	No Person	With Person	Single	Multi.
Real	30.43%	69.57%	41.30%	58.70%	32.61%	67.39%	76.09%	23.91%	47.83%	52.17%
Not Real	30.77%	69.23%	23.08%	76.92%	30.77%	69.23%	69.23%	30.77%	46.15%	53.85%

Table 6.1 shows that there are not much differences between the two groups at the decision points #1, #3, and #5. There is a little difference at the decision point #4. But about 69% of the subjects who did not feel real still avoided the threatening individual and about 76% of the subjects who felt real did the same. There is a relatively big difference at the decision point #2. About 41% of those who felt real chose the street without a hidden space whereas only about 23% of those who felt not real did the same. This shows that the hidden space did not generate fear in the subjects who did not feel real as much as in the subjects who felt real. The role of a hidden space needs further investigation since we originally thought that it would generate much fear so that most of the subjects would avoid the street with a hidden space. Although there are some ratio difference between the two groups in the choice of routes at the decision point #2, more than half of both groups chose the street with a hidden space. The rest of the decision points do not show much difference. Thus, it is not necessary to distinguish these two groups in analyzing the experimental results.

6.3 Statistical Analysis of Results

In this section, we present the statistical analysis of our experimental results. Chi-square tests of gender differences and age differences and their statistical significances are described.

6.3.1 Chi-square (χ^2) Tests

To investigate the statistical significance of our experimental results, we used Chi-square tests which are used mostly to analyze data that contain counts and frequencies [20]. First, a null hypothesis is set up assuming either only pure chance would affect outcome variables or other probabilities would fit the observed frequencies. When the null hypothesis is not supported by the experimental results, these results are statistically significant and need our attention. There are two kinds of Chi-square tests: one is Chi-square tests for goodness-of-fit which investigates the proportion of cases that fall into the various categories of a single variable, the other, Chi-square tests for independence which finds out whether two categorical variables are related [84]. The statistics program SPSS version 16.0 was used, which came with many different analysis tools including Chi-square tests and Generalized Linear Models.

We tried to apply Chi-square tests to the data for all subjects. However, it was difficult to identify a realistic null hypothesis. We instructed the subjects to navigate to the destination as quickly as possible (the shortest path), so it could be argued that the null hypothesis (in the absence of fear) was that 100% of subjects would choose the shortest path. However, the Chi-square test does not apply if all choose the same path. In addition, we gave the subjects an additional instruction that they should choose one of the two routes at each decision point according to their judgment as if they had really been in that environment. Based on this, it can be argued that the probability of choosing one of the routes is somewhere between 50% and 100%. Since we do not know the exact probability, we are not able to set up a null hypothesis to apply Chi-square tests to all subjects. Fortunately, the actual data is quite easy to interpret - except at the decision point #5 it is not difficult to see a significant difference at each decision point by just looking at Figure 6.5.

We used the Chi-square tests for gender (male and female subjects). Our null hypothesis is that there is no difference between male and female subjects in making a decision at each decision point. Table 6.2 shows the summary of the tests. The decision points #1 and #2 show the gender difference in making choices of the routes.

The Chi-square tests is used for age (the subjects who were under 30 years old and who were 30 years old or older). Our null hypothesis is that there is no difference between the subjects who were under 30 years old and the subjects who were 30 year old or older in making a decision at each decision point. Table 6.3 is the summary of the tests and shows

Table 6.2: Chi-square test for male and female subjects.

	Pearson Chi-Square			Continuity Correction				
DP	**Value**	**df**	**Asymp. Sig (2)**	**Value**	**df**	**Asymp. Sig (2)**	**N**	**Stat. Sig.**
#1	6.287	1	0.012	4.906	1	0.027	59	Yes ($p < 0.05$)
#2	8.392	1	0.004	6.8567	1	0.009	59	Yes ($p < 0.05$)
#3	1.218	1	0.270	0.665	1	0.415	59	No ($p > 0.05$)
#4	0.757	1	0.384	0.314	1	0.575	59	No ($p > 0.05$)
#5	0.603	1	0.437	0.257	1	0.612	59	No ($p > 0.05$)

no statistical significance at any decision point for these two different age groups.

Table 6.3: Chi-square test for subjects who are under 30 and who are 30 or older.

	Pearson Chi-Square			Continuity Correction				
DP	**Value**	**df**	**Asymp. Sig (2)**	**Value**	**df**	**Asymp. Sig (2)**	**N**	**Stat. Sig.**
#1	0.425	1	0.514	0.136	1	0.712	59	No ($p > 0.05$)
#2	0.192	1	0.661	0.029	1	0.866	59	No ($p > 0.05$)
#3	2.199	1	0.138	1.451	1	0.228	59	No ($p > 0.05$)
#4	0.674	1	0.412	0.273	1	0.602	59	No ($p > 0.05$)
#5	0.845	1	0.358	0.434	1	0.510	59	No ($p > 0.05$)

6.4 Shortest Path and Longest Path

Figure 6.10 is an example of the shortest path that one of the subjects navigated. As we mentioned earlier, if you follow the shortest path, you have to choose a more fear generating route than the other one at each decision point except the decision point #5 even though we originally thought subjects would be more afraid of multiple people than a single person. But it seems that that is not the case according to the experimental results. We collected and analyzed all subjects who followed the shortest path. A total of 10 subjects (17% of all subjects) took the shortest path.

Figure 6.11 shows the gender and age differences for the subjects who took the shortest path. More male subjects took the shortest path than female subjects but a Chi-square test for gender does not show statistical significance (See Appendix A). There is no statistical significance in age difference either.

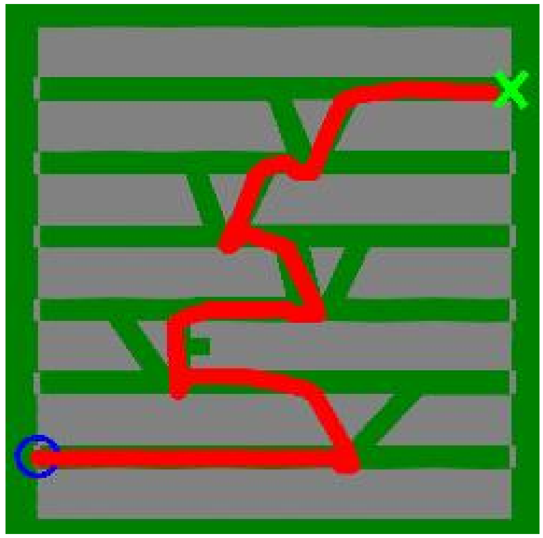


Figure 6.10: An example of the shortest path.

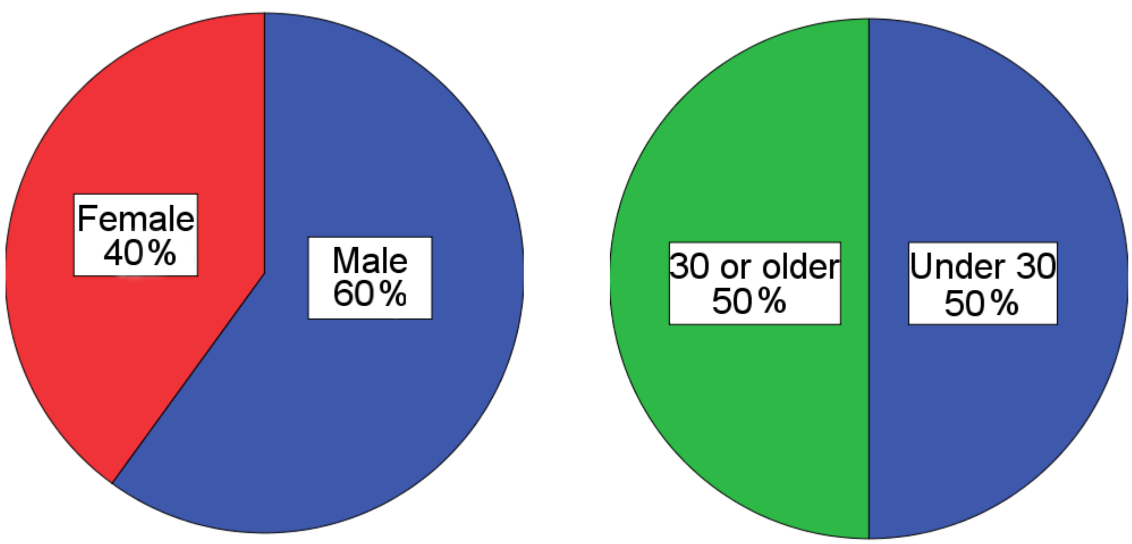


Figure 6.11: Gender and age differences for the subjects who took the shortest path.

Figure 6.12 shows two examples of the longest path. If you choose a safer route at each decision point, you would take the longest path. But since it turned out that there is no clear distinction between a safer route and a more dangerous route at the decision point #5, we included both routes at the decision point #5 for our longest path. A total of 17 subjects (29% of all subjects) took the longest path.

Figure 6.13 shows the gender and age differences for the subjects who took the longest path. Many more female subjects followed the longest path than male subjects and a Chi-square test for gender also shows statistical significance. Even though more of the subjects who were 30 years old or older took the longest path than the subjects who were under 30 years old, a Chi-square test does not show statistical significance.

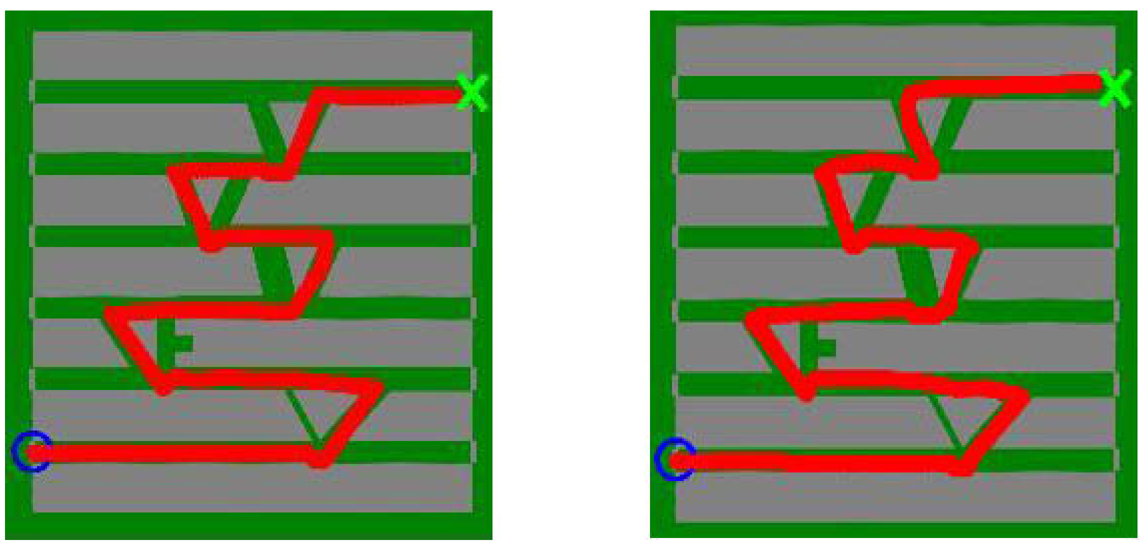


Figure 6.12: Examples of the longestest path.

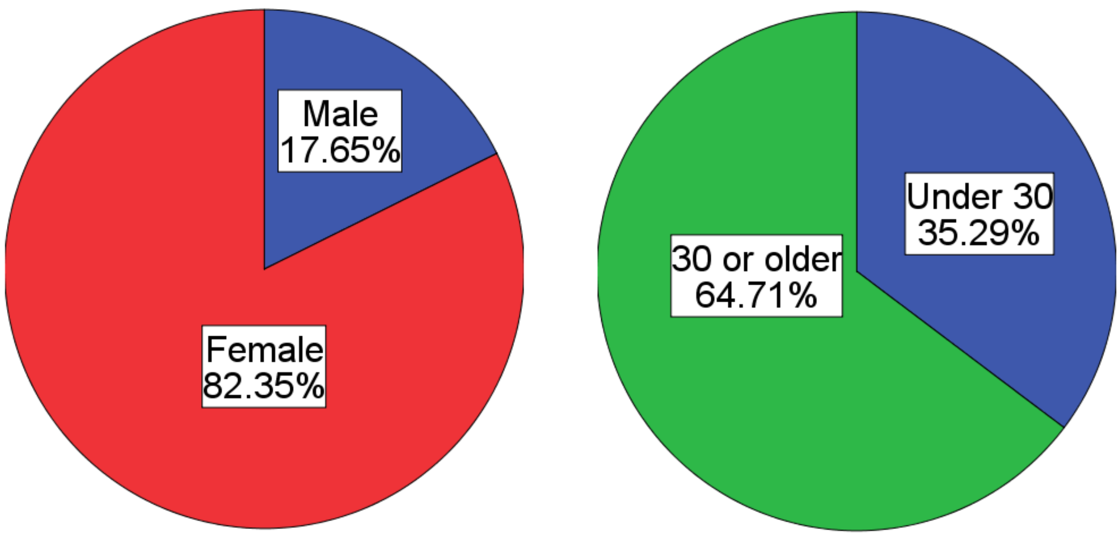


Figure 6.13: Gender and age differences for the subjects who took the longest path.

6.5 Content Analysis of Post-experimental Interviews

We used content analysis to analyze our transcripts of the interviews that were done with our participants after the experiments. We could have done structured interviews that would generate predefined question-answer pairs with which our analysis would have been easier. However, in this kind of interviews, researchers' notions are imposed on the interviewees either consciously or unconsciously, who are not able to express the reasons for their choices freely. Contrarily, in open-ended interviews, interviewees are permitted to speak freely in their own terms. We chose to use open-ended interviews with our participants because we wanted to find any reasons for their choices that we might not have expected. To discover those reasons, we need to perform content analysis on the transcripts of the interviews.

Grounded theory is briefly surveyed in this section because many elements of grounded theory were adopted in the course of conducting the post-experimental interviews and developing the coding scheme.

6.5.1 Content Analysis

Definition

Content analysis is a research technique for condensing many words of text into fewer content categories based on explicit rules of coding by making replicable and valid inferences [104, 63]. For the replicable and valid inferences, researchers use analytical constructs, or rules of inference, which can be either explicit or implicit, to answer the research questions by making correspondences between data and context. Content analysis can be used not only for textual analysis but also for any data that are durable in nature such as actions recorded in video tapes or drawings and paintings.

Quantitative and Qualitative

There are two kinds of content analysis: quantitative and qualitative. Quantitative content analysis considers something measurable (countable) such as word frequencies, space measurements (e.g. column inches that newspapers devoted to particular subject matters), and length of broadcasting time (e.g. radio and television). However, quantitative content analysis has a limitation. For example, the assumption behind word frequency is that the words that are mentioned most often are the words that reflect the great concerns in the context [104]. This assumption maybe be true in some cases. However, in many cases, synonyms are used for stylistic reasons and this might mislead researchers and cause them to miss important concepts. In addition, the words chosen for counting may not well represent categories. Another possible problem is that some words may have multiple meanings and should be understood in context. Maybe a quantitative approach is needed at the beginning of the content analysis, but qualitatively contextualizing what the text really means is necessary in the light of what is known about the circumstances surrounding the text because each body of the text is unique, allows multiple interpretations, and needs to be treated accordingly [63]. Thus, the process of the qualitative content analysis is iterative: researchers try to answer their research questions by rearticulating, recontextualizing, reinterpreting, and even redefining the research questions in the course of their involvement with the given text. They support their interpretations by weaving quotes from the analyzed text into their conclusion. Sometimes mixed methods of both are used to complement each other.

Procedure of Content Analysis

There are slightly different procedures depending on whether we choose quantitative or qualitative analysis. The general steps that quantitative content analysis uses are as follows [123]:

- Establish hypotheses: a researcher generates hypotheses from related research, existing/relevant theory, and/or related expertise domain.
- Identify data for analysis: a researcher determines the nature of the data to test the hypotheses. (e.g. interviews or existing documents)
- Select a sampling method and sample units: a researcher chooses a proper sampling method to generalize his/her hypotheses that will be tested on a limited data set (e.g. random sampling or convenience sampling). Sampling units are information-bearing instances that are distinguished for selective inclusion in an analysis [63] (e.g. individual human subjects or issues of newspapers).
- Create a coding scheme: a researcher develops a coding scheme before coding begins. In making a coding scheme, he/she develops categories and defines coding/recoding units. A coding scheme can be developed either by preliminary examination of the

data (emergent) or based on some theory (a priori). Coding/recoding units are distinguished for separate description, transcription, recording, or coding (e.g. words, sentences, paragraphs, articles, or letters) [63]. These units can have different levels. Categories require mutual exclusiveness and exhaustiveness. When categories are mutually exclusive, no unit falls between two categories and each unit is represented by only one category. Exhaustive categories should be able to describe all recoding/coding units without exception [104]. A codebook (coding instructions) may also be developed for coders at this stage.

- Train coders: a researcher trains coders who may not be familiar with terms in which they should code the data. They need to learn to work with the codebook as their only guide [63]. In the course of training, the codebook, the structure of the data, and/or any other training material can be amended or corrected.

- Code data: a researcher administers all the details of coding procedures such as preparing all the necessary material for coders, managing the state of the record, checking coders' mistakes, and collecting the coded data from coders and organizing them in the orderly manner.

- Analyze the coded data with appropriate statistical techniques: a researcher summarizes and structuralize the findings from the coded data so that they become applicable to his/her hypotheses. He/she also identifies relationships between the findings and relates them to other situations and studies [123]. Many different statistical techniques can be used to present the findings such as tabulations, cross-tabulations, correlations, or multi-variate techniques.

- Write a report: a researcher writes the details of his/her analysis and results in the report.

Procedures for qualitative content analysis are similar to those of quantitative content analysis. Both of them do sampling, unitizing, and contextualizing with specific research questions in mind. However, since quantitative content analysis is iterative and inductive, generating hypotheses is not its immediate purpose [123]. Rather, a researcher starts the analysis with open (foreshadowing) questions and identifies concepts and patterns emerging from the text by scrutinizing it. Sampling in qualitative content analysis is theoretical and purposive, focusing on the uniqueness of the text with the possibility of the multiple interpretations. Seeing transferability rather than generalizability, a researcher reiterates the data until he/she thinks all the patterns are found. He/she tries to find the "big picture" of the phenomenon by carefully incorporating the context, the population, the situation, and the theoretical construct. The results are usually presented using either simple tabulations or cross-tabulations or the gradual accretion of details within his/her textual presentation without any numbers [123].

Reliability and Validity

When something is reliable, it means it generates the same or compatible results in different experiments and trials. In content analysis, reliability can be described by three characteristics: stability, reproducibility, and accuracy [63]. Stability, or intra-rater reliability, is the degree to which a process is unchanging over time. Good stability means the same coder can get the same results repeatedly by following the coding procedure. Reproducibility, or inter-rater reliability, is the degree to which a process can be replicated by different coders working under different conditions and locations, or using equivalent measuring instruments. For example, when different coders tend to code the same text into the same category, it has high reproducibility. Accuracy is the degree to which a process conforms to its specifications and generates what it is supposed to generate. One of the ways to measure reliability is to measure the percentage of agreement among coders (raters) [104].

Validity is the degree to which quality of research results leads us to accept them as true as speaking about the real-world people and phenomena. There are known relationships between reliability and validity [63]:

- Unreliability limits the chance of validity.
- Reliability does not guarantee validity.
- In the pursuit of high reliability, validity tends to get lost.

6.5.2 Grounded Theory

Our approach to this present research as a whole involves a traditional, deductive method, which is constructing a hypothesis or proposition from the previous studies and then validating it by research experiments to examine whether that hypothesis is true or false. The hypothesis of our research is that the behaviour of the pedestrian model developed based on the social science findings would reflect that of real human pedestrians. However, our approach in seeking reasons for subjects' choice of routes is an inductive approach (content analysis), close to grounded theory.

Grounded theory was developed by Glaser and Strauss while they collaborated in research on dying hospital patients [40]. It is a systematic qualitative comparative research methodology emphasizing the emergence of a theory from raw data during the process of research. Some researchers consider grounded theory as one of the most widely used forms of (qualitative) content analysis [98]. In grounded theory, a researcher does not start with a hypothesis or any assumption. The researcher develops a conceptual framework from the data rather than from previous studies [105]. He/she also tries to identify dominant processes in the social phenomena rather than focusing on individual units. The collected data is compared to other data and the direction of collecting data can be modified as a hypothesis is being evolved. The research process is recursive between data collection and data analysis rather than following linear steps. The researcher tries to be involved with the people whom he/she is studying and understands them subjectively instead of being a detached observer.

The coding procedures of grounded theory are important because coded data leads to the development of concepts [7]. Concepts are groups of codes that have similar content. Concepts then lead to broader categories (groups of similar concepts), properties (of the categories), hypothesis, and ultimately to theory. There are three stages of coding: open coding, axial coding, and selective coding.

- First stage: Open coding is identifying, naming (labeling), categorizing, and describing phenomena found in the data (gathering categories and their properties).
- Second stage: Axial coding is the process of creating subcategories and finding relationships among categories and subcategories (properties) (linking categories to subcategories).
- Third stage: Selective coding is the process of selecting core categories that can contain other categories (integrating and refining categories).

Conceptual ordering involves organizing data into discrete categories according to a selective and specified set of properties and their dimensions and then explaining them these categories using descriptions [107]. It is an important step in theorizing or can be the end point of analysis in some cases. In the final state, researchers are encouraged to use the literature to confirm findings and to identify differences between the research results and the literature.

6.5.3 Detailed Content Analysis of the Interviews

In order to analyze the post experimental interviews using content analysis, we first transcribed interviews that had been videotaped. The sound quality of some interviews was satisfactory but that of the others was less so due to participants' low and mumbling voices so that we had to use a sound enhancer and watch carefully their lips and gestures to find out what they had said. It was good that the night vision feature of the camcorder was used to videotape the participants during the experiments and the interviews.

After transcribing the 59 interviews, a coding scheme was developed by preliminary examination of the transcribed interviews. We then had to decide what should be our coding units. They could be words, phrases, paragraphs, or an entire interview. By testing each option, it was decided to use an whole interview for each subject as a coding unit, thinking that we could discover more accurate reasons from the context of the interviews.

The next step was to develop exclusive and exhaustive categories. Categories that earlier fear of crime research studies had developed were used and our own categories were added by examining the transcribed interviews. This was a recursive process, testing some sample interviews with the categories and adding, removing, and modifying them. A codebook (coding instructions) was also developed for coders and each category was defined with a clear meaning. Since 59 interviews for each decision point should be coded (total 295 coding units), a coding program (CODY) was developed in VB.net to code in an organized and systematic manner (Figure 6.14). Three coders were chosen, intentionally including a coder who was not familiar with the content of our research for the validation of our content analysis. The coders were trained and instructed to follow the same coding scheme and coded the interviews independently using the coding program.

To analyze the coded interviews, a code analyzing program (CODEANALYZER) was also developed in VB.net so that they could easily be analyzed (Figure 6.15). Since our coding was open-ended (meaning that coders can choose as many variables as they find), it was difficult to evaluate our inter-rater reliability using the existing scheme. To address this, our own scheme of evaluating inter-rater (inter-coder) reliability was devised. For example,

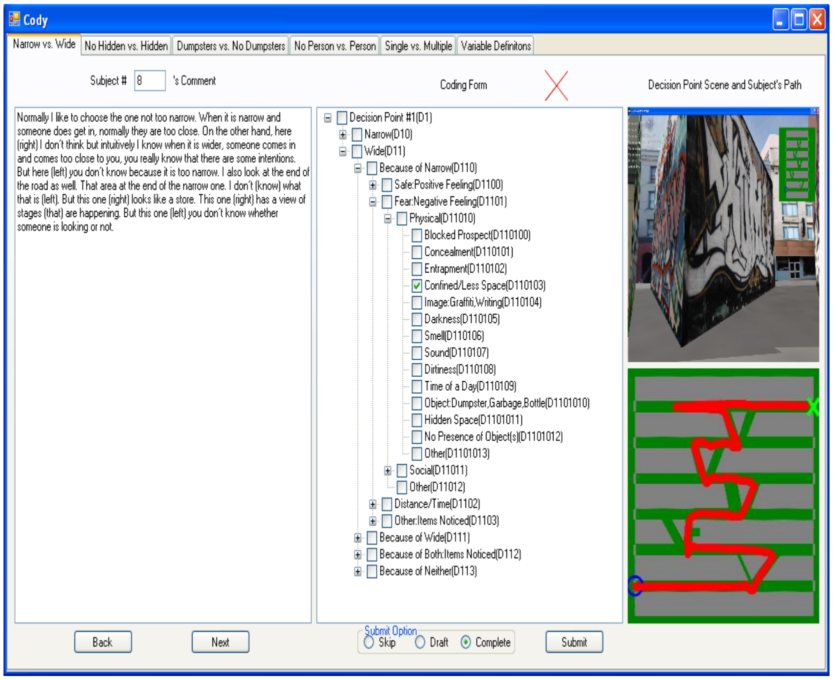


Figure 6.14: A coding program (CODY).

Coder A chooses the variables a, and b, and Coder B, variables b, c, and d. We select Coder A as our frame of reference because he/she has the smaller number of variables, which is 2. This is a reasonable choice because it can be thought that Coder B simply chooses more extra variables. Variables of Coders A and B are compared to see how many variables agree each other, which is just 1. Thus, % of agreement is $1/2 = 50\%$. We used this scheme for three coders. If two of the three coders agreed on their coding per category per subject, we considered it as a valid coding.

When the grounded theory method is applied to our research, we did not follow every step of the procedures of grounded theory in the strict sense. However, in a broader sense, we adopted many elements of this approach in the process of conducting, collecting, analyzing the interview data. First of all, open ended interviews were conducted because we did not want to impose our pre-conceived ideas on the subjects. We simply asked them, "Why did you choose this route instead of the other route?" And the subjects freely talked about the reasons for their choices (sometimes they shared their personal stories and experiences that had led such choices). In this way, we discovered things that we did not expected at

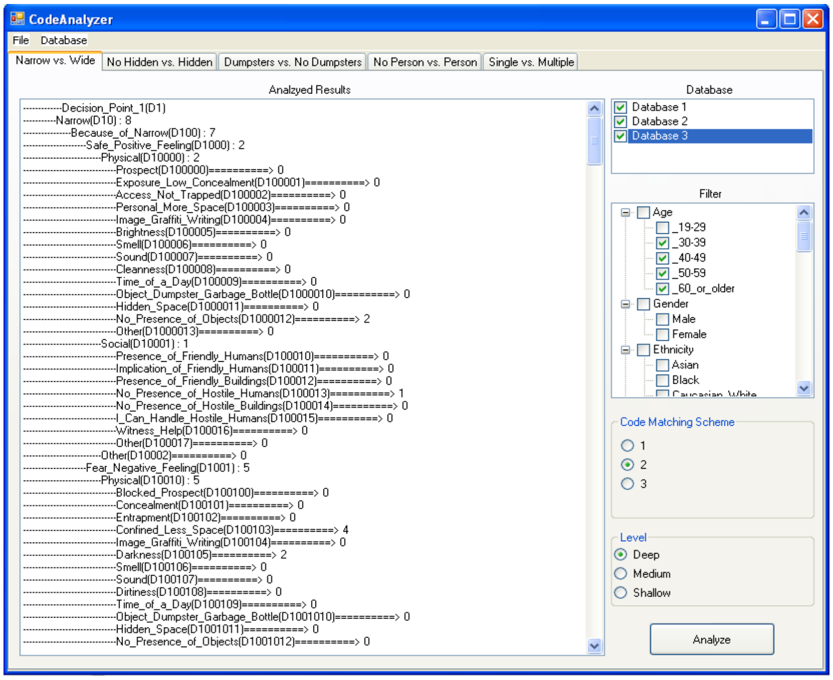


Figure 6.15: A code analyzing program (CODEANALYZER).

the beginning. In the course of coding the data (the transcribed interview data), we followed pretty much the same stages of grounded theory that were mentioned above: Creating categories and subcategories, finding the relationships among them, and selecting core categories. We did these procedures recursively by adding, removing, modifying, and combining categories as we were developing a coding scheme.

6.5.4 Content Analysis for All Subjects

Table 6.4 shows some of the top reasons given by all subjects for choosing a particular route at each decision point. First of all, it is important to know how to read the table. The two major columns show which route the subjects chose at each decision point. In each column there are lists of the reasons why the subjects chose that route. Sometimes they talked about likes and dislikes about the route that they chose whereas at other times they mentioned the route that they did not choose. To indicate whether what the subjects said was positive or negative feeling, we put either p or n in the brackets respectively. At the end of each decision point, we also indicated in parentheses the number of subjects who mentioned that reason.

At the decision point #1, the top reason for choosing the wide street was that subjects liked personal space or more space in the wide street. And they did not like confined or less space in the narrow street. The top reason for choosing the narrow street was that the narrow street was short, fast, and closer to the destination. It is interesting to see that some of the subjects' comments are paradoxical. 8 of the subjects who chose the narrow street had a negative feeling about confined, less space in the narrow street but still chose the narrow one.

At the decision point #2, the number one reason for choosing the street with a hidden space was that the street was short, fast, and closer to the destination even though most of them noticed the hidden space. Some top reasons for choosing the street without a hidden space were: implication of hostile humans in the hidden space, friendly buildings in the street without a hidden space, and dislike about the hidden space.

At the decision point #3, the top reasons for choosing the street without dumpsters were negative feelings about dumpsters, garbage, and bottles in the street and implication of hostile humans and concealment in the street. Those who chose the street with dumpsters chose that street because it was short, fast, and closer to the destination even though some of them noticed dumpsters, garbage, and bottles.

At the decision point #4, 75% of the subjects chose the street without a threatening person because: the person might do something or talk unexpectedly, and/or he is intoxicated with drugs or alcohol. They did not like the sound that he was making and his vomitting. A few subjects chose the street with the threatening person because of the economic reason in distance.

At the decision point #5, we have interesting observations. About half of the subjects saw multiple people as a kind of threat whereas the other half felt more comfortable with them instead of a single person. They felt the opposite about the single person. Some people felt a positive feeling about the multiple people because they could witness or help in case of trouble.

Table 6.4: Content analysis for reasons of route choices (all subjects).

Decision Point	**Reasons**	
#1	*Narrow (31%)*	*Wide (69%)*
	narrow: short, closer, fast (16)	wide: personal, more space [p] (35)
	narrow: confined, less space [n] (8)	narrow: confined, less space [n] (27)
		narrow: darkness [n] (7)
		wide: long, far, slow (6)
		narrow: hostile buildings [n] (6)
		wide: friendly buildings [p] (6)
	% of Agreement: 79.08%	
#2	*No Hidden Space(37%)*	*Hidden Space(63%)*
	hidden: implication of hostile humans [n] (9)	hidden: short, closer, fast (29)
	no hidden: friendly buildings [p] (9)	hidden: hidden space noticed (25)
	hidden: hidden space [n] (9)	hidden: dumpster, garbage, bottle noticed (12)
	hidden: image, graffiti, writing [n] (6)	hidden: image, graffiti, writing noticed (8)
	% of Agreement: 85.28%	
#3	*Dumpsters (32%)*	*No Dumpsters (68%)*
	dumpsters: short, closer, fast (15)	dumpsters: dumpsters, garbage, bottle [n] (30)
	dumpster, garbage, bottle noticed (10)	dumpsters: implication of hostile humans [n] (28)
		dumpsters: concealment [n] (24)
		dumpsters: smell [n] (15)
		dumpsters: dirtiness [n] (11)
		no dumpsters: cleanness [p] (7)
		no dumpsters: prospect [p] (7)
		no dumpsters: long, far, slow (6)
	% of Agreement: 84.62%	
#4	*No Person Present(75%)*	*Person Present(25%)*
	person: unexpected behaviour, talk [n] (20)	person: person noticed (8)
	person: intoxication of drugs, alcohol [n] (20)	person: short, closer, fast (6)
	person: sound [n] (13)	
	person: vomit [n] (10)	
	person: sickness, pain [n] (8)	
	% of Agreement: 87.31%	
#5	*Single Person(47%)*	*Multiple People(53%)*
	multiple: multiple people [n] (21)	single: hostile dress, appearance [n] (17)
	single: single person alone [p] (19)	multiple: multiple people [p] (16)
	single: can handle hostile human [p] (8)	multiple: friendly dress, appearance [p] (14)
	multiple: don't want to distract humans [n] (7)	single: single person alone[n] (12)
		multiple: witness, help [p] (10)
		single: no witness, no help [n] (8)
		multiple: friendly activity [p] (8)
		multiple: short, closer, fast (6)
	% of Agreement: 84.66%	

6.5.5 Content Analysis for Male Subjects

Table 6.5 reveals the reasons male subjects gave for choosing a particular route at each decision point. At the decision point #1, half of the male subjects chose the wide street because they were comfortable with the street that has personal space or more space. The other half chose the narrow street because the street was short, fast, and closer to the destination.

At the decision point #2, 86% of the male subjects chose the street with a hidden space because it was the shortest path even though they noticed the hidden space and felt that hostile humans might be there.

At the decision point #3, 59% of the male subjects went to the street without dumpsters because of their negative feelings about dumpsters, garbage, and bottles, and implication of hostile humans and concealment. 41% of the male subjects chose the street with dumpsters because of the economic reason. It is interesting to see that some of the subjects mentioned a bad smell in the street with dumpsters even though our VE system did not produce any smell.

At the decision point #4, 68% of the male subjects chose the street without a threatening person with the reasons like the person's unexpected behaviour or talk, his (coughing) sound, and/or his intoxication with drugs or alcohol. But 32% of the subjects still chose the street with the threatening person because the street was the shortest path.

At the decision point #5, we see the same reasons that were seen for all subjects. However, a little bit more than half of the male subjects chose the street with multiple people. Some subjects made a choice based on their careful observation of people's dress, outward appearance, and activity.

Table 6.5: Content analysis for reasons of route choices (male subjects).

Decision Point	**Reasons**	
#1	*Narrow (50%)*	*Wide (50%)*
	narrow: short, closer, fast (10) narrow: confined, less space [n] (5) both: image, graffiti, writing noticed (3)	wide: personal, more space [p] (11) narrow: confined, less space [n] (8) both: image, graffiti, writing noticed (4) wide: long, far, slow (4)
	% of Agreement: 79.08%	
#2	*No Hidden Space(14%)*	*Hidden Space(86%)*
		hidden: hidden space noticed (13) hidden: short, closer, fast (12) hidden: dumpster, garbage, bottle noticed (6) hidden: implication of hostile humans [n] (3) hidden: hidden space [n] (3) both: space-same size, width, length (3) hidden: image, graffiti, writing noticed (3)
	% of Agreement: 85.28%	
#3	*Dumpsters (41%)*	*No Dumpsters (59%)*
	dumpsters: short, closer, fast (9) dumpsters: dumpster, garbage, bottle noticed (4) dumpsters: smell [n] (3)	dumpsters: dumpsters, garbage, bottle [n] (11) dumpsters: implication of hostile humans [n] (10) dumpsters: concealment [n] (8) dumpsters: smell [n] (7) no dumpsters: long, far, slow (4) dumpsters: dirtiness [n] (3) no dumpsters: prospect [p] (3)
	% of Agreement: 84.62%	
#4	*No Person Present(68%)*	*Person Present(32%)*
	person: unexpected behaviour, talk [n] (10) person: sound [n] (7) person: intoxication of drugs, alcohol [n] (7) person: sickness, pain [n] (4) person: smell [n] (3) person: vomit [n] (3)	person: short, closer, fast (4) person: person noticed (4)
	% of Agreement: 87.31%	
#5	*Single Person(41%)*	*Multiple People(59%)*
	multiple: multiple people [n] (7) single: can handle hostile human [p] (5) multiple: can't handle hostile humans [n] (4) single: single person alone [p] (4)	multiple: multiple people [p] (9) single: single person alone [n] (7) multiple: short, closer, fast (6) single: hostile dress, appearance [n] (6) multiple: friendly activity [p] (5) multiple: friendly dress, appearance [p] (5) single: no witness, no help [n] (4) multiple: witness, help [p] (4)
	% of Agreement: 84.66%	

6.5.6 Content Analysis for Female Subjects

Table 6.6 shows the reasons given by female subjects for choosing a particular route at each decision point. At the decision point #1, 81% of the female subjects chose the wide street because of more personal space in the wide street and the confined and less space in the narrow street. They did not like darkness and hostile buildings in the narrow street but liked brightness in the wide street.

At the decision point #2, 51% of the female subjects went to the street without a hidden space because of friendly buildings and brightness in the wide street and implication of hostile humans in the hidden space. 49% of the subjects went the street with the hidden space due to the economic reason even though most of them noticed the hidden space.

At the decision point #3, 73% of the female subjects chose the street without dumpsters because they did not like dumpsters, garbage, bottles, implication of hostile humans, and concealment.

At the decision point #4, 78% of the female subjects chose the street without a threatening individual for the same reasons as the male subjects.

At the decision point #5, about half of the female subjects went to the street with a single person and the other half, the street with multiple people. Those who went to the street with a single person felt comfortable with the single person, but did not feel easy with the multiple people. Some of them did not want to distract the multiple people. Some of the top reasons of those who went to the street with multiple people were people's dress or outward appearance.

Table 6.6: Content analysis for reasons of route choices (female subjects).

Decision Point	**Reasons**	
#1	*Narrow (19%)*	*Wide (81%)*
	narrow: short, closer, fast (6)	wide: personal, more space [p] (24)
	narrow: confined, less space [n] (3)	narrow: confined, less space [n] (13)
		narrow: darkness [n] (7)
		narrow: hostile buildings [n] (6)
		wide: friendly buildings [p] (6)
		wide: brightness [p] (3)
		both: image, graffiti, writing [n] (3)
	% of Agreement: 79.08%	
#2	*No Hidden Space(51%)*	*Hidden Space(49%)*
	no hidden: friendly buildings [p] (8)	hidden: short, closer, fast (17)
	hidden: implication of hostile humans [n] (7)	hidden: hidden space noticed (12)
	hidden: hidden space [n] (7)	hidden: dumpster, garbage, bottle noticed (6)
	no hidden: brightness [p] (5)	hidden: image, graffiti, writing noticed (5)
	no hidden: implication of friendly humans [p] (5)	both: item noticed (3)
	hidden: image, graffiti, writing [n] (4)	
	hidden: dumpster, garbage, bottle [n] (4)	
	hidden: concealment [n] (4)	
	hidden: no friendly humans [n] (3)	
	no hidden: no hostile humans [p] (3)	
	% of Agreement: 85.28%	
#3	*Dumpsters (27%)*	*No Dumpsters (73%)*
	dumpster, garbage, bottle noticed (6)	dumpsters: dumpsters, garbage, bottle [n] (19)
	dumpsters: short, closer, fast (6)	dumpsters: implication of hostile humans [n] (18)
	both: item noticed (4)	dumpsters: concealment [n] (16)
	dumpsters: dumpster, garbage, bottle [n] (3)	dumpsters: dirtiness [n] (8)
	dumpsters: concealment [n] (3)	dumpsters: smell [n] (8)
	dumpsters: implication of hostile humans [n] (3)	no dumpsters: cleanness [p] (5)
		no dumpsters: prospect [p] (4)
	% of Agreement: 84.62%	
#4	*No Person Present(78%)*	*Person Present(22%)*
	person: intoxication of drugs, alcohol [n] (13)	person: person noticed (4)
	person: unexpected behaviour, talk [n] (10)	virtual, not real (3)
	person: vomit [n] (7)	
	person: sound [n] (6)	
	person: sickness, pain [n] (4)	
	person: hostile human (other) [n] (4)	
	person: hostile dress, appearance [n] (3)	
	% of Agreement: 87.31%	
	Single Person(51%)	*Multiple People(49%)*
	single: single person alone [p] (15)	single: hostile dress, appearance [n] (11)
	multiple: multiple people [n] (14)	multiple: friendly dress, appearance [p] (9)
	multiple: don't want to distract humans [n] (6)	multiple: multiple people [p] (7)

#5	single: friendly dress, appearance [p] (5) multiple: hostile activity [n] (3) single: can handle hostile human [p] (3)	multiple: witness, help [p] (6) single: single person alone [n] (5) single: no witness, no help [n] (4) multiple: friendly activity [p] (3) multiple: separation [p] (3)
	% of Agreement: 84.66%	

6.5.7 Content Analysis for Subjects under 30 Years Old

Table 6.7 reveals the reasons given by the subjects who were under 30 years old for choosing a particular route at each decision point. At the decision point #1, 66% of the subjects chose the wide street because they liked more personal space in the wide street and did not like the confined and limited space in the narrow street. 34% of the subjects went to the narrow street because it was short, fast, and closer to the destination.

At the decision point #2, 66% of the subjects went to the street with a hidden space because it was short, fast, and closer to the destination even though many of them noticed the hidden space and other objects. 34% of the subjects went to the street without a hidden space because they had a negative feeling about the implication of hostile humans in the street with the hidden space and did not like the hidden space and graffiti there. They liked the friendly buildings in the street without a hidden space.

At the decision point #3, 59% of the subjects went to the street without dumpsters because they did not like dumpsters, garbage, and bottles, and had a negative feeling about the implication of hostile humans and concealment. Some of them made negative comments about smell and dirtiness in the street with dumpsters. 41% of the subjects chose the street with dumpsters because it was short, fast, and closer to the destination even though some of them noticed dumpsters, garbage, and bottles there and others did not like them.

At the decision point #4, 79% of the subjects chose the street without a threatening person because they did not like the person's unexpected behaviour or talk and/or his intoxication with drugs or alcohol. Some of them did not like his sound, vomit, and/or smell. 21% of the subjects chose the street with a threatening person because it was short, fast, and closer to the destination.

At the decision point #5, 59% of the subjects went to the street with multiple people because they had a positive feeling about the multiple people and their friendly dress, outward appearance and/or friendly activity, but did not like the single person and/or his hostile dress or outward appearance. Some of them mentioned that they could have a witness or help with the multiple people but not with the single person if anything happened. 41% of the subjects chose the street with the single person because they had a negative feeling about the multiple people but a positive feeling about the single person. Some of them thought they could handle a single person in case of trouble but not multiple people.

Table 6.7: Content analysis for reasons of route choices (subjects under 30).

Decision Point	**Reasons**	
#1	*Narrow (34%)*	*Wide (66%)*
	narrow: short, closer, fast (10) narrow: confined, less space [n] (4) both: image, graffiti, writing noticed (4)	wide: personal, more space [p] (17) narrow: confined, less space [n] (15) wide: long, far, slow (4) both: image, graffiti, writing noticed [n] (3) both: image, graffiti, writing noticed (3) narrow: hostile buildings [n] (3) narrow: implication of hostile humans [n] (3)
	% of Agreement: 79.08%	
#2	*No Hidden Space(34%)*	*Hidden Space(66%)*
	hidden: implication of hostile humans [n] (6) hidden: hidden space [n] (6) no hidden: friendly buildings [p] (4) hidden: image, graffiti, writing [n] (4)	hidden: short, closer, fast (15) hidden: hidden space noticed (11) hidden: dumpster, garbage, bottle noticed (6) hidden: implication of hostile humans [n] (4) hidden: hidden space [n] (3)
	% of Agreement: 85.28%	
#3	*Dumpsters (41%)*	*No Dumpsters (59%)*
	dumpsters: short, closer, fast (9) dumpsters: dumpster, garbage, bottle noticed (7) dumpsters: dumpster, garbage, bottle [n] (3)	dumpsters: dumpster, garbage, bottle [n] (14) dumpsters: implication of hostile humans [n] (13) dumpsters: concealment [n] (11) dumpsters: smell [n] (8) dumpsters: dirtiness [n] (5)
	% of Agreement: 84.62%	
#4	*No Person Present(79%)*	*Person Present(21%)*
	person: unexpected behaviour, talk [n] (13) person: intoxication of drugs, alcohol [n] (12) person: sound [n] (10) person: vomit [n] (4) person: smell [n] (3)	person: short, closer, fast (4)
	% of Agreement: 87.31%	
#5	*Single Person(41%)*	*Multiple People(59%)*
	multiple: multiple people [n] (9) single: single person alone [p] (9) single: can handle hostile human [p] (4) multiple: can't handle hostile humans [n] (3)	multiple: friendly dress, appearance [p] (10) multiple: multiple people [p] (10) single: hostile dress, appearance [n] (8) multiple: friendly activity [p] (7) single: single person alone [n] (6) multiple: witness, help [p] (5) single: no witness, no help [n] (4) multiple: short, closer, fast (3) single: hostile posture [n] (3)
	% of Agreement: 84.66%	

6.5.8 Content Analysis for Subjects, 30 Years Old or older

Table 6.8 shows the reasons given by the subjects who were 30 years old or older for choosing a particular route at each decision point. At the decision point #1, 73% of the subjects chose the wide street because they liked more personal space in the wide street, but did not like confined and less space in the narrow street. Some of them had a positive feeling about the friendly buildings in the wide street and a negative feeling about darkness in the narrow street. 27% of the subjects went to the narrow street because it was short, fast, and closer to the destination even though some of them did not like confined and less space.

At the decision point #2, 60% of the subjects went to the street with a hidden space because it was short, fast, and closer to the destination even though they noticed the hidden space and graffiti and other objects. 40% of the subjects went to the street without a hidden space because they liked the friendly buildings in that street and thought that there might be friendly humans there.

At the decision point #3, 77% of the subjects chose the street without dumpsters because they did not like dumpsters, garbage, and bottles, the implication of hostile humans, and/or concealment in the street with dumpsters. Some of them did not like smell and/or dirtiness in that street but liked a good prospect and cleanness in the street without dumpsters. 23% of the subjects went to the street with dumpsters because it was short, fast, and closer to the destination even though some of them noticed dumpsters, garbage, and bottles.

At the decision point #4, 70% of the subjects went to the street without a threatening person because they did not like the person's intoxication with drugs or alcohol and/or his unexpected behaviour, talk, vomit, and/or sickness or pain. 30% of othe subjects chose the street with the person even though they noticed him.

At the decision point #5, 53% of the subjects chose the street with a single person because they had a negative feeling about the multiple people but a positive feeling about the single person. Some of them did not want to distract the multiple people and thought that they could handle the single person in case of trouble. 47% of the subjects chose the street with multiple people because they did not like the single person's hostile dress or appearance. Some of them had a positive feeling about the multiple people but a negative feeling about the single person. They also thought that they could have a witness or help with the multiple people but not with the single person. They also liked the multiple people's friendly dress or appearance.

Table 6.8: Content analysis for reasons of route choices (subjects, 30 or older).

Decision Point	**Reasons**	
#1	*Narrow (27%)*	*Wide (73%)*
	narrow: short, closer, fast (6) narrow: confined, less space [n] (4)	wide: personal, more space [p] (18) narrow: confined, less space [n] (12) wide: friendly buildings [p] (6) narrow: darkness [n] (5) wide: brightness [p] (3) narrow: hostile buildings [n] (3)
	% of Agreement: 79.08%	
#2	*No Hidden Space(40%)*	*Hidden Space(60%)*
	no hidden: implication of friendly humans [p] (5) no hidden: friendly buildings [p] (5) hidden: implication of hostile humans [n] (3) no hidden: brightness [p] (3) hidden: hidden space [n] (3) hidden: image, graffiti, writing [n] (3) hidden: concealment [n] (3)	hidden: hidden space noticed (14) hidden: short, closer, fast (14) hidden: image, graffiti, writing noticed (7) hidden: dumpster, garbage, bottle noticed (6) both : item noticed (3)
	% of Agreement: 85.28%	
#3	*Dumpsters (23%)*	*No Dumpsters (77%)*
	dumpsters: short, closer, fast (6) both: item noticed (3) dumpsters: dumpster, garbage, bottle noticed (3)	dumpsters: dumpsters, garbage, bottle [n] (16) dumpsters: implication of hostile humans [n] (15) dumpsters: concealment [n] (13) dumpsters: smell [n] (7) dumpsters: dirtiness [n] (6) no dumpsters: prospect [p] (5) no dumpsters: cleanness [p] (4)
	% of Agreement: 84.62%	
#4	*No Person Present(70%)*	*Person Present(30%)*
	person: intoxication of drugs, alcohol [n] (8) person: unexpected behaviour, talk [n] (7) person: vomit [n] (6) person: sickness, pain [n] (6) person: sound [n] (3)	person: person noticed (7)
	% of Agreement: 87.31%	
#5	*Single Person(53%)*	*Multiple People(47%)*
	multiple: multiple people [n] (12) single: single person alone [p] (10) multiple: don't want to distract humans [n] (5) single: can handle hostile human [p] (4) single: friendly dress, appearance [p] (3) single: hostile dress, appearance [n] (3)	single: hostile dress, appearance [n] (9) multiple: multiple people [p] (6) single: single person alone [n] (6) multiple: witness, help [p] (5) multiple: friendly dress, appearance [p] (4) single: no witness, no help [n] (4) multiple: short, closer, fast (3)
	% of Agreement: 84.66%	

Chapter 7

Discussion of Principal Findings

In this chapter, some of the important findings from our experimental results are highlighted and their implications are discussed. A new pedestrian model based on the new findings is proposed.

7.1 Model Validation

Our pedestrian model was developed based on a broadly based review of the social science literature. But the model does not explicitly represent either male or female subjects or either young or older subjects. It simply distinguishes three different personalities (bold, normal, or fearful), with the thought that this would be a better approach because there are males who are more fearful than females and vice versa as well as different age groups having the same issues. In fact, some of such cases were found from our experimental results.

In general, our experimental results validate our pedestrian model but the following comments apply:

- It was assumed that bold pedestrians would not mind passing through fearful environmental features (or the features that seem to be fearful), as a result, taking the shortest path. Our analysis shows that 17% of all subjects took the shortest path. Their main reason for choosing the shortest path was that it was short, fast and closer to the destination. Compared to other subjects who took different routes and their comments, we can say these subjects are relatively bolder than the others. The pedestrian model simulation with "Bold" threshold (Figure 4.6) demonstrated such behaviour, taking the shortest path.

- It was also expected that fearful pedestrians would avoid all fearful environmental features such as a narrow street or alley, a street with a hidden space, a street with dumpsters, a street with a threatening individual, and a street with multiple threatening individuals, as a result, taking the longest path. 17% of all subjects took this longest path. Our content analysis shows that the subjects expressed their negative feelings about these features. But at the decision point #5, there was no clear distinction between the street with a single threatening individual and the street with multiple threatening individuals in deciding which one is more fearful. 53% of all subjects felt the street with multiple individuals is safer whereas 43% of the subjects felt the other way. If both routes are included as a part of the longest path, 29% of all subjects followed this path.

- Based on the literature review, it was anticipated that social incivility, such as threatening people, would generate more fear than physical incivility, such as a hidden space or dumpsters. This idea was employed in our pedestrian model by assigning different fear weight values to different environmental features. Thus, the pedestrian model demonstrated this behaviour showing more fear toward people than objects. Our analysis shows that 75% of all subjects avoided a threatening individual at the decision point #4 whereas 69% of the subjects avoided the narrow street at the decision point#1 and 68% of them did not go to the street with dumpsters at the decision point #3. During the post experimental interviews, many subjects mentioned that they were more afraid of threatening individuals than any physical features or objects. The decision point #5 has social incivility on both routes and was setup for a different test purpose. But many subjects made a comment that they did not want to choose either of them at the decision point #5, which shows that social incivility generates much fear. The results at the decision point #2 were unexpected and will be discussed later.

7.2 Confirmation of Previous Findings and New Findings

Many fear of crime research studies show that women have a higher level of fear than men. Our experimental results confirm this finding. In particular, there was statistical significance in gender difference at the decision points #1 and #2. Only half of the male subjects chose the wide street whereas 81% of the female subjects went to that street. In contrast to the decision #1, about half of the female subjects chose the street with a hidden space whereas 86% of the male subjects chose that street. At the decision points #3 and #4, the female subjects are still higher in percentage in choosing safer routes. This behaviour shows that women are more afraid of fearful environmental features than men.

Many findings of fear of crime research also indicate that generally as people grow older they tend to be more fearful. But our experimental results do not show any statistical significance in age difference at any decision point. Although the subjects who were 30 years or older are a little bit higher in percentage in avoiding physical incivility than the subjects who were under 30 years old, the younger subjects show a little bit higher in percentage in avoiding social incivility at the decision point #4 than the older subjects. However, our experimental results affirm Evans' study showing that in cases of stranger attacks and sexual attacks, the younger people tend to be more fearful than the older people although in cases of mugging and break and enter, it is the other way around [31].

Now we discuss the results at the decision point #2. It was originally thought that a hidden space would generate such fear that many people would avoid the street with the hidden space. But the results show 63% of all subjects went to that street. In particular, 86% of all male subjects chose that street. Our content analysis shows that many subjects noticed the hidden space as well as graffiti and a dumpster there. Many female subjects who chose the street without a hidden space mentioned that they were afriad of the implication of hostile humans in the hidden space. Then why did many subjects choose to go to the street with the hidden space? One possible explanation about this behaviour comes from a study by Herzog and Flynn-Smith [50] mentioned in the background chapter. Their study about urban alleys shows that mystery about a hidden space plays a paradoxical role. In other words, people feel it is dangerous to go towards the unknowns of the hidden space. At the same time, they also feel curious about them. This paradoxical role for mystery is context dependent. When we analyze the context of the decision point #2, it was during the bright day time and there was no dark shadow on the hidden space. Thus, curiosity about the hidden space was stronger than the danger of it. In fact, some of the subjects who chose the street with the hidden space mentioned that if it had been a night time, they would have chosen the street without a hidden space.

The decision point #5 is an interesting situation. It was originally thought that multiple threatening individuals would create more fear than a single threatening individual. But our experimental results show that this is not the case—the decision making proved to be rather complicated. Some people felt comfortable with multiple people but uncomfortable with a single person whereas others felt the opposite. It was not just numbers that played in their decision. The subjects carefully observed people's dress, appearance, posture, and activity to find out whether the person or the people are friendly or hostile. They also calculated whether they could handle the person or people in case of trouble and whether there would be any witness or help if anything would happen. If the single person turned out to be a possible offender, there would be no help or witness. In the case of multiple people, some subjects were interested in knowing whether they were separate or together, thinking that if they were separate and one group would attack, the other group could witness or help, but not so in the case of their being together. Most of the subjects took more time making a choice of the routes at the decision point #5. There was a cognitive process going on in the subjects' minds, deciding which route would be safer than the other one. However, why did the subjects see the same person and people totally differently? This is another research question that needs further investigation. It is not statistically significant but we notice that rather more than half of the female subjects and the subjects who were 30 years old or older chose the street with a single threatening individual whereas it was opposite with the male subjects and the subjects who were under 30 years old. It seems that the young, male subjects tended to avoid a confrontation with a single threatening person one on one.

7.3 Use of a Virtual Environment (VE)

The original reason for using a VE for our experiments was that there was no other obvious options. We could not find any relevant research cases that could be tested against our model or observe real people in a real environment with a desirable experimental setting. But it turned out that developing and using a virtual urban environment provided us with a number of benefits:

- First of all, the experimental results show that a VE can be a good replacement for a real environment. Here we are not saying that a VE is better than or equivalent to a real environment. Rather a VE is good enough to be used for research studies when it is properly developed and set up. When it was decided to use a VE instead of a real environment, we were not sure whether or not it would work. Due to the limitation of our research funds and time, we could not hire a professional 3D model developer. Instead, we simply mapped the textures from photographs taken from a well-known fear-generating area onto 3D buildings. During the pilot studies, we found that subjects felt more presence with a big screen than a small monitor or a small screen. Using a wireless Wii remote controller was another important factor for the subjects to feel presence. While sitting down and using a keyboard and a mouse is like playing a game, standing and controlling with a Wii controller makes subjects feel as if they were navigating in a real environment. Making a confined experimental space without any distraction was also important to create presence. Traffic background sounds added additional realism. It is also noted that the experimenter's attitude was important to make subjects engage in the experiments seriously.

- The findings of this study suggests that a VE can be a useful new research tool for many different research studies, especially in criminology. Many research studies related to crime or fear of crime have possible ethical issues because of the risk of danger involved, and thus cannot be realized. But if we use a VE, we can overcome such issues. In addition, we can save time and cost by using a VE for research experiments. It is also relatively easy to change the setup of a VE such as adding more virtual people or changing the configuration of buildings and parks. We can also set the program to record the subjects' behaviour in the VE during the experiments. As virtual reality technology is advanced and related equipments get cheaper, it becomes easier to develop and set up a more realistic VE for research studies.

7.4 New Findings Lead to a New Pedestrian Model

As noted in the earlier chapters, the initial prototype of our pedestrian model was based on a variety of findings from social science: Fear-generating environmental features such as narrow passageways without escape routes, hidden spaces, and garbage dumpsters and threatening individuals influence pedestrians' choice of routes. In the course of validating the model with human subjects in a VE, we noticed additional aspects that affect the behaviour of pedestrians:

- Buildings in the background or at the end of streets influence pedestrians' choice of routes. People prefer bright, well-maintained, and friendly buildings to dark, abandoned, and hostile buildings. For example, many subjects chose the streets that have bright stores at the end instead of abandoned buildings with blocked, dark doors and windows.

- Graffiti and writings on the wall affect pedestrians' behaviour although they do not generate as much fear as threatening individuals.
- Whether streets are dirty or clean influences pedestrians' behaviour. When streets are dirty with garbage and bottles (and possibly syringes), people tend to avoid those streets.
- Bad smell is another factor that people dislike. Streets that emit bad odor imply that those streets are not well maintained and can be crime-vulnerable areas.
- Sound can be a negative factor that influences pedestrians' choice of routes. A threatening individual's painful coughing sound drove away many subjects.
- Whether the outward appearance and activity of a person are friendly or hostile affects pedestrians' behaviour. Even though subjects' judgment on these factors were not consistent, they took them seriously in making a decision.
- When there are multiple people on the street, pedestrians observe carefully whether they are together or separated. If they seem to be together, it generates more fear whereas if they seem to be separated, it generates less fear.

In addition to the social science findings that we have already employed in the model, these findings should be considered in the development of a new pedestrian model. Some of them can easily be included in the model whereas others need further investigation. These findings might be useful for future urban planning as well. For example, the configuration of background buildings at the end of streets can be considered in planning since they influence pedestrians' choice of routes.

7.5 A Proposed New Pedestrian Model

The initial prototype of our pedestrian model served its purpose well in this research. Since we have now better insights into pedestrians' behaviour, an articulated and enhanced pedestrian model can to be developed based on the new findings. The following are the proposed features that can be included in the new model.

- The pedestrian model needs an enhanced sensor component. The visual sense of the initial prototype detects any obstacles on the way, senses width and hidden spaces and identifies different objects and threatening individuals. But the new findings require the visual sense to identify graffiti and writings on the wall, and distinguish between brightness and darkness, between friendly buildings and hostile buildings, between cleanness and dirtiness, and between friendly dress, outward appearance, and activity of people and hostile ones of people. It also needs to recognize multiple people and their spatial configuration (whether they are together or separate).

- The sensor component needs to have multiple senses. Since smell and sound play significantly in decision-making, the model requires the senses of audition and olfaction.

- An articulated fear/risk assessment component is needed. Since much information comes from the surrounding environment through multiple senses, the fear/risk assessment cannot be a simple, linear process anymore, which is just recognizing one environmental feature or threatening individuals. When the data of multiple environmental features come in at the same time, the fear/risk assessment component should be able to process the data in a comprehensive manner based on the model's personality type and on the dynamically generated fear weight values for multiple objects and environmental features by comparing these objects and features one with another.

- The personality component needs to be articulated. Since our experimental results show gender difference in pedestrians' choice of routes, we can have a personality that represents typical females and a personality that represents typical males. In addition, we can articulate these personalities by adjusting some of the variables so that we can have different personality types such as a bold female pedestrian or a fearful male pedestrian.

- The cognitive map component and the planning component need to be flexible. With the initial prototype, there were some cases where the model was stuck in some corners or could not move anymore because cells with high cost values around the fear-generating objects or features block all the possible paths. For example, even though two routes both generate fear, a real pedestrian may choose one of them to reach his/her destination (or go back home). Thus, a new model should be able to reassess the situation and choose one of the routes (or go back to his/her starting position).

- Visualization can be improved by having a better animation with realistic characters and environments. When a model character is fearful, an animation that shows fear can be generated.

Chapter 8

Conclusions and Future Work

In this chapter, we set out the conclusions from this research and present proposals for future work.

8.1 Conclusions

In this thesis, we presented a pedestrian model that was developed based on social science findings in criminology and environmental psychology related to fear of crime. The related literature review presented findings on CPTED, fear of crime, social science modeling and simulation, VR, and pedestrian simulation. We then described how the model was developed, implemented, and simulated. The behaviour of the pedestrian model in simulations reflected the social science findings. We then described how the model was validated through experiments with human subjects using a VE. The experimental methodology was explained and the details of the experiments were described. We showed how the experimental results were analyzed using statistical techniques and content analysis. The experimental results and their analyses confirmed some of the findings in the literature and provided new findings. We then proposed a new pedestrian model based on the new findings.

In general, the prototype of our pedestrian model was validated through the experiments with human subjects using a VE. The experimental results show that bold pedestrians took the shortest path, and did not mind passing by fearful environmental features while fearful pedestrians followed longer paths, avoiding such features. It is also confirmed that social incivility generates more fear than physical incivility. There was an unexpected result regarding hidden spaces because many subjects chose the street with a hidden space. A possible explanation was provided for this exception in Chapter 7, which is based on the paradoxical role of a hidden space and time of a day. The effect of multiple threatening individuals on pedestrians turned out to be rather complicated. Friendliness or hostility was judged by pedestrians through feeling or reasoning about multiple threatening individuals' dress, posture, activity, togetherness, and so on. Gender differences were found in pedestrians' choice routes, but no significant age differences were found. This confirms that females are generally more cautious and fearful than males. Content analysis revealed reasons for pedestrians' choices of their routes (some were obvious but others were not). For example, graffiti, background buildings, sound, and bad smells influence pedestrians' choices of routes. Another conclusion that we can make is that a VE can be a good replacement for a real environment for research studies, particularly studies in criminology. Using a VE opens a whole new world of research studies that has not been possible before because of cost, time, and ethical issues.

8.2 Future Work

This research suggests many possible research studies for the future. These include:

- The new pedestrian model that was proposed in the previous chapter should be implemented, simulated, and validated.
- A new simulation system should be implemented in a way that it is more flexible and updatable so that more complicated models can be more easily simulated in the system.
- The new pedestrian model and the simulation system should be implemented in a more objective, modular way so that they can be more robust and scalable.
- A VE can be made more realistic by making it dirtier and by adding more (animated) human figures and cars.
- We could do the same experiments with the same VE but change the time of a day to a night time by adjusting lighting in the VE.
- Different kinds of hidden spaces can be investigated using a VE. For example, we can place a shadow over a hidden space or put visible litter, syringes, and/or garbage

in a hidden space from the view angle of a subject and see whether these make any difference.

- We can further investigate what makes buildings friendly or hostile such as brightness, colors, degrees of ruins, building types, and so on.
- We can also elaborate on what makes people friendly or hostile such as gender, age, ethnicity, dress, activity, and so on.
- A pedestrian's perception of multiple people in a street can be examined. We can test for a different number of people, a different spatial configuration of people, different ethnic groups, different genders, different ages, and so on.
- The behaviour of multiple pedestrians can be studied, modeled, simulated, and validated. We expect that when multiple pedestrians navigate together in an urban environment, their fear of crime would be different (probably lower) from that of a single pedestrian.
- The effect of different sounds and smells on fear of crime can be tested.
- Another, rather different, aspect that might be investigated involves the way virtual environments are constructed. Our current approach based on the way most VE's are constructed, uses a complete 3D model of the world. This allows great flexibility but a rich detailed environment requires a very powerful computer with a lot of memory. Also, a lot of effort is required to create the details of the environment. An alternate approach would be to use a digital video and/or digital photographs to create a panoramic view of the background for the environment and to only provide 3D computer models for foreground objects and figures.

Appendix A

Statistical analysis

We present here our statiscal analysis of our experimental data.

A.1 Chi-square Test for Gender

The following tables show Chi-square test for male and female subjects using SPSS 16.0.

Table A.1: Crosstabulation for gender and D1.

Gender		D1 Narrow	Wide	Total
Male	Count	11	11	22
	% within Gender	50.0%	50.0%	100.0%
	% within D1	61.1%	26.8%	37.3%
	% of Total	18.6%	18.6%	37.3%
Female	Count	7	30	37
	% within Gender	18.9%	81.1%	100.0%
	% within D1	38.9%	73.2%	62.7%
	% of Total	11.9%	50.8%	62.7%
Total	Count	18	41	59
	% within Gender	30.5%	69.5%	100.0%
	% within D1	100.0%	100.0%	100.0%
	% of Total	30.5%	69.5%	100.0%

Table A.2: Chi-square test for gender and D1.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	6.287[a]	1	0.012		
Continuity Correction[b]	4.906	1	0.027		
Likelihood Ratio	6.191	1	0.013		
Fisher's Exact Test				0.019	0.014
Linear-by-Linear Association	6.180	1	0.013		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 6.71.

[b]Computed only for a 2x2 table

Table A.3: Crosstabulation for gender and D2.

		D2		
Gender		No Hidden	With Hidden	Total
Male	Count	3	19	22
	% within Gender	13.6%	86.4%	100%
	% within D2	13.6%	51.4%	37.3%
	% of Total	50.8%	32.2%	37.3%
Female	Count	19	18	37
	% within Gender	51.4%	48.6%	100%
	% within D2	86.4%	48.6%	62.7%
	% of Total	32.2%	30.5%	62.7%
Total	Count	22	37	59
	% within Gender	37.3%	62.7%	100%
	% within D2	100%	100%	100%
	% of Total	37.3%	62.7%	100%

Table A.4: Chi-square test for gender and D2.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.392[a]	1	0.004		
Continuity Correction[b]	6.857	1	0.009		
Likelihood Ratio	9.144	1	0.002		
Fisher's Exact Test				0.005	0.003
Linear-by-Linear Association	8.2500	1	0.004		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 8.20.

[b]Computed only for a 2x2 table

Table A.5: Crosstabulation for gender and D3.

		D3		
Gender		With Dumpsters	No Dumpsters	Total
Male	Count	9	13	22
	% within Gender	40.9%	59.1%	100%
	% within D3	47.4%	32.5%	37.3%
	% of Total	15.3%	22.0%	37.3%
Female	Count	10	27	37
	% within Gender	27.0%	73.0%	100%
	% within D3	52.6%	67.5%	62.7%
	% of Total	16.9%	45.8%	62.7%
Total	Count	19	40	59
	% within Gender	32.2%	67.8%	100%
	% within D3	100%	100%	100%
	% of Total	32.2%	67.8%	100%

Table A.6: Chi-square test for gender and D3.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.218[a]	1	0.270		
Continuity Correction[b]	0.665	1	0.415		
Likelihood Ratio	1.202	1	0.273		
Fisher's Exact Test				0.388	0.207
Linear-by-Linear Association	1.197	1	0.274		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 7.08.

[b]Computed only for a 2x2 table

Table A.7: Crosstabulation for gender and D4.

		D4		
Gender		No Person	With Person	Total
Male	Count	15	7	22
	% within Gender	68.2%	31.8%	100%
	% within D4	34.1%	46.7%	37.3%
	% of Total	25.4%	11.9%	37.3%
Female	Count	29	8	37
	% within Gender	78.4%	21.6%	100%
	% within D4	65.9%	53.3%	62.7%
	% of Total	49.2%	13.6%	62.7%
Total	Count	44	15	59
	% within Gender	74.6%	25.4%	100%
	% within D4	100%	100%	100%
	% of Total	74.6%	25.4%	100%

Table A.8: Chi-square test for gender and D4.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.757[a]	1	0.384		
Continuity Correction[b]	0.314	1	0.575		
Likelihood Ratio	0.744	1	0.388		
Fisher's Exact Test				0.537	0.285
Linear-by-Linear Association	0.744	1	0.388		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 5.59.

[b]Computed only for a 2x2 table

Table A.9: Crosstabulation for gender and D5.

		D5		
Gender		Single	Multiple	Total
Male	Count	9	13	22
	% within Gender	40.9%	59.1%	100%
	% within D5	32.1%	41.9%	37.3%
	% of Total	15.3%	22.0%	37.3%
Female	Count	19	18	37
	% within Gender	51.4%	48.6%	100%
	% within D5	67.9%	58.1%	62.7%
	% of Total	32.2%	30.5%	62.7%
Total	Count	28	31	59
	% within Gender	47.5%	52.5%	100%
	% within D5	100%	100%	100%
	% of Total	47.5%	52.5%	100%

Table A.10: Chi-square test for gender and D5.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.603[a]	1	0.437		
Continuity Correction[b]	0.257	1	0.612		
Likelihood Ratio	0.606	1	0.436		
Fisher's Exact Test				0.591	0.307
Linear-by-Linear Association	0.593	1	0.441		
N of Valid Cases	59				

[a] 0 cells (.0%) have expected count less than 5. The minimum expected count is 10.44.

[b] Computed only for a 2x2 table

A.2 Chi-square Test for Age

The following tables show Chi-square Test for subjects who are younger than 30 years old and who are 30 years old or older using SPSS 16.0.

Table A.11: Crosstabulation for age and D1.

Age		D1 Narrow	Wide	Total
Under 30	Count	10	19	29
	% within Age	34.5%	65.5%	100%
	% within D1	55.6%	46.3%	49.2%
	% of Total	16.9%	32.2%	49.2%
30 or older	Count	8	22	30
	% within Age	26.7%	73.3%	100%
	% within D1	44.4%	53.7%	50.8%
	% of Total	13.6%	37.3%	50.8%
Total	Count	18	41	59
	% within Age	30.5%	69.5%	100%
	% within D1	100%	100%	100%
	% of Total	30.5%	69.5%	100%

Table A.12: Chi-square test for age and D1.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.425[a]	1	0.514		
Continuity Correction[b]	0.136	1	0.712		
Likelihood Ratio	0.425	1	0.514		
Fisher's Exact Test				0.580	0.356
Linear-by-Linear Association	0.418	1	0.518		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 8.85.

[b]Computed only for a 2x2 table

Table A.13: Crosstabulation for age and D2.

Age		D2 No Hidden	D2 With Hidden	Total
Under 30	Count	10	19	29
	% within Age	34.5%	65.5%	100%
	% within D2	45.5%	51.4%	49.2%
	% of Total	16.9%	32.2%	49.2%
30 or older	Count	12	18	30
	% within Age	40.0%	60.0%	100%
	% within D2	54.5%	48.6%	50.8%
	% of Total	20.3%	30.5%	50.8%
Total	Count	22	37	59
	% within Age	37.3%	62.7%	100%
	% within D2	100%	100%	100%
	% of Total	37.3%	62.7%	100%

Table A.14: Chi-square test for age and D2.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.192[a]	1	0.661		
Continuity Correction[b]	0.029	1	0.866		
Likelihood Ratio	0.192	1	0.661		
Fisher's Exact Test				0.789	0.433
Linear-by-Linear Association	0.189	1	0.664		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 10.81.

[b]Computed only for a 2x2 table

Table A.15: Crosstabulation for age and D3.

Age		D3 With Dumpsters	D3 No Dumpsters	D3 Total
Under 30	Count	12	17	29
	% within Age	41.4%	58.6%	100%
	% within D3	63.2%	42.5%	49.2%
	% of Total	20.3%	28.8%	49.2%
30 or older	Count	7	23	30
	% within Age	23.3%	76.7%	100%
	% within D3	36.8%	57.5%	50.8%
	% of Total	11.9%	39.0%	50.8%
Total	Count	19	40	59
	% within Age	32.2%	67.8%	100%
	% within D3	100%	100%	100%
	% of Total	32.2%	67.8%	100%

Table A.16: Chi-square test for age and D3.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.199[a]	1	0.138		
Continuity Correction[b]	1.451	1	0.228		
Likelihood Ratio	2.218	1	0.136		
Fisher's Exact Test				0.170	0.114
Linear-by-Linear Association	2.162	1	0.141		
N of Valid Cases	59				

[a]0 cells (.0%) have expected count less than 5. The minimum expected count is 9.34.

[b]Computed only for a 2x2 table

Table A.17: Crosstabulation for age and D4.

Age		D4 No Person	D4 With Person	Total
Under 30	Count	23	6	29
	% within Age	79.3%	20.7%	100%
	% within D4	52.3%	40.0%	49.2%
	% of Total	39.0%	10.2%	49.2%
30 or older	Count	21	9	30
	% within Age	70.0%	30.0%	100%
	% within D4	47.7%	60.0%	50.8%
	% of Total	35.6%	15.3%	50.8%
Total	Count	44	15	59
	% within Age	74.6%	25.4%	100%
	% within D4	100%	100%	100%
	% of Total	74.6%	25.4%	100%

Table A.18: Chi-square test for age and D4.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.674[a]	1	0.412		
Continuity Correction[b]	0.273	1	0.602		
Likelihood Ratio	0.678	1	0.410		
Fisher's Exact Test				0.552	0.302
Linear-by-Linear Association	0.663	1	0.416		
N of Valid Cases	59				

[a] 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.37.

[b] Computed only for a 2x2 table

Table A.19: Crosstabulation for age and D5.

Age		D5 Single	Multiple	Total
Under 30	Count	12	17	29
	% within Age	41.4%	58.6%	100%
	% within D5	42.9%	54.8%	49.2%
	% of Total	20.3%	28.8%	49.2%
30 or older	Count	16	14	30
	% within Age	53.3%	46.7%	100%
	% within D5	57.1%	45.2%	50.8%
	% of Total	27.1%	23.7%	50.8%
Total	Count	28	31	59
	% within Age	47.5%	52.5%	100%
	% within D5	100%	100%	100%
	% of Total	47.5%	52.5%	100%

Table A.20: Chi-square test for age and D5.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.845[a]	1	0.358		
Continuity Correction[b]	0.434	1	0.510		
Likelihood Ratio	0.847	1	0.357		
Fisher's Exact Test				0.438	0.255
Linear-by-Linear Association	0.831	1	0.362		
N of Valid Cases	59				

[a] 0 cells (.0%) have expected count less than 5. The minimum expected count is 13.76.

[b] Computed only for a 2x2 table

Appendix B

Coding Scheme

Content analysis categories (variables) for the decision point #1 that were used to code the interviews are presented here in order to show how we have coded the data. Categories of other decision points are similar to those of the decision point #1 with a few different categories.

```
-----------Narrow(D10)
----------------Because_of_Narrow(D100)
---------------------Safe_Positive_Feeling(D1000)
--------------------------Physical(D10000)
-------------------------------Prospect(D100000)
-------------------------------Exposure_Low_Concealment(D100001)
-------------------------------Access_Not_Trapped(D100002)
-------------------------------Personal_More_Space(D100003)
-------------------------------Image_Graffiti_Writing(D100004)
-------------------------------Brightness(D100005)
-------------------------------Smell(D100006)
-------------------------------Sound(D100007)
-------------------------------Cleanness(D100008)
-------------------------------Time_of_a_Day(D100009)
-------------------------------Object_Dumpster_Garbage_Bottle(D1000010)
-------------------------------Hidden_Space(D1000011)
-------------------------------No_Presence_of_Objects(D1000012)
-------------------------------Other(D1000013)
--------------------------Social(D10001)
-------------------------------Presence_of_Friendly_Humans(D100010)
-------------------------------Implication_of_Friendly_Humans(D100011)
-------------------------------Presence_of_Friendly_Buildings(D100012)
-------------------------------No_Presence_of_Hostile_Humans(D100013)
-------------------------------No_Presence_of_Hostile_Buildings(D100014)
-------------------------------I_Can_Handle_Hostile_Humans(D100015)
```

```
-------------------------------Witness_Help(D100016)
-------------------------------Other(D100017)
--------------------------Other(D10002)
---------------------Fear_Negative_Feeling(D1001)
--------------------------Physical(D10010)
-------------------------------Blocked_Prospect(D100100)
-------------------------------Concealment(D100101)
-------------------------------Entrapment(D100102)
-------------------------------Confined_Less_Space(D100103)
-------------------------------Image_Graffiti_Writing(D100104)
-------------------------------Darkness(D100105)
-------------------------------Smell(D100106)
-------------------------------Sound(D100107)
-------------------------------Dirtiness(D100108)
-------------------------------Time_of_a_Day(D100109)
-------------------------------Object_Dumpster_Garbage_Bottle(D1001010)
-------------------------------Hidden_Space(D1001011)
-------------------------------No_Presence_of_Objects(D1001012)
-------------------------------Other(D1001013)
--------------------------Social(D10011)
-------------------------------Presence_of_Hostile_Humans(D100110)
-------------------------------Implication_of_Hostile_Humans(D100111)
-------------------------------Presence_of_Hostile_Buildings(D100112)
-------------------------------No_Presence_of_Friendly_Humans(D100113)
-------------------------------No_Presence_of_Friendly_Buildings(D100114)
-------------------------------I_Cant_Handle_Hostile_Humans(D100115)
-------------------------------No_Witness_No_Help(D100116)
-------------------------------Other(D100117)
--------------------------Other(D10012)
---------------------Distance_Time(D1002)
--------------------------Long_Far_Slow(D10020)
--------------------------Short_Closer_Fast(D10021)
---------------------Other_Items_Noticed(D1003)
--------------------------Hidden_Space(D10030)
--------------------------Image_Graffit_Writing(D10031)
--------------------------Smell(D10032)
--------------------------Sound(D10033)
--------------------------Time_of_a_Day(D10034)
--------------------------Object_Dumpster_Garbage_Bottle(D10035)
--------------------------Presence_of_Humans(D10036)
--------------------------Implication_of_Humans(D10037)
--------------------------Presence_of_Buildings(D10038)
--------------------------No_Presence_of_Humans(D10039)
--------------------------No_Presence_of_Buildings(D100310)
--------------------------No_Presence_of_Objects(D100311)
--------------------------Other(D100312)
----------------Because_of_Wide(D101)
```

```
---------------------Safe_Positive_Feeling(D1010)
--------------------------Physical(D10100)
-------------------------------Prospect(D101000)
-------------------------------Exposure_Low_Concealment(D101001)
-------------------------------Access_Not_Trapped(D101002)
-------------------------------Personal_More_Space(D101003)
-------------------------------Image_Graffiti_Writing(D101004)
-------------------------------Brightness(D101005)
-------------------------------Smell(D101006)
-------------------------------Sound(D101007)
-------------------------------Cleanness(D101008)
-------------------------------Time_of_a_Day(D101009)
-------------------------------Object_Dumpster_Garbage_Bottle(D1010010)
-------------------------------Hidden_Space(D1010011)
-------------------------------No_Presence_of_Objects(D1010012)
-------------------------------Other(D1010013)
--------------------------Social(D10101)
-------------------------------Presence_of_Friendly_Humans(D101010)
-------------------------------Implication_of_Friendly_Humans(D101011)
-------------------------------Presence_of_Friendly_Buildings(D101012)
-------------------------------No_Presence_of_Hostile_Humans(D101013)
-------------------------------No_Presence_of_Hostile_Buildings(D101014)
-------------------------------I_Can_Handle_Hostile_Humans(D101015)
-------------------------------Witness_Help(D101016)
-------------------------------Other(D101017)
--------------------------Other(D10102)
---------------------Fear_Negative_Feeling(D1011)
--------------------------Physical(D10110)
-------------------------------Blocked_Prospect(D101100)
-------------------------------Concealment(D101101)
-------------------------------Entrapment(D101102)
-------------------------------Confined_Less_Space(D101103)
-------------------------------Image_Graffiti_Writing(D101104)
-------------------------------Darkness(D101105)
-------------------------------Smell(D101106)
-------------------------------Sound(D101107)
-------------------------------Dirtiness(D101108)
-------------------------------Time_of_a_Day(D101109)
-------------------------------Object_Dumpster_Garbage_Bottle(D1011010)
-------------------------------Hidden_Space(D1011011)
-------------------------------No_Presence_of_Objects(D1011012)
-------------------------------Other(D1011013)
--------------------------Social(D10111)
-------------------------------Presence_of_Hostile_Humans(D101110)
-------------------------------Implication_of_Hostile_Humans(D101111)
-------------------------------Presence_of_Hostile_Buildings(D101112)
-------------------------------No_Presence_of_Friendly_Humans(D101113)
```

```
-------------------------------No_Presence_of_Friendly_Buildings(D101114)
-------------------------------I_Cant_Handle_Hostile_Humans(D101115)
-------------------------------No_Witness_No_Help(D101116)
-------------------------------Other(D101117)
--------------------------Other(D10112)
---------------------Distance_Time(D1012)
--------------------------Long_Far_Slow(D10120)
--------------------------Short_Closer_Fast(D10121)
---------------------Other_Items_Noticed(D1013)
--------------------------Hidden_Space(D10130)
--------------------------Image_Graffit_Writing(D10131)
--------------------------Smell(D10132)
--------------------------Sound(D10133)
--------------------------Time_of_a_Day(D10134)
--------------------------Object_Dumpster_Garbage_Bottle(D10135)
--------------------------Presence_of_Humans(D10136)
--------------------------Implication_of_Humans(D10137)
--------------------------Presence_of_Buildings(D10138)
--------------------------No_Presence_of_Humans(D10139)
--------------------------No_Presence_of_Buildings(D101310)
--------------------------No_Presence_of_Objects(D101311)
--------------------------Other(D101312)
----------------Because_of_Both_Items_Noticed(D102)
---------------------Hidden_Space(D1020)
--------------------------Positive(D1020-0)
--------------------------Neutral(D1020-1)
--------------------------Negative(D1020-2)
---------------------Image_Graffiti_Writing(D1021)
--------------------------Positive(D1021-0)
--------------------------Neutral(D1021-1)
--------------------------Negative(D1021-2)
---------------------Brightness(D1022)
---------------------Darkness(D1023)
---------------------Smell(D1024)
--------------------------Positive(D1024-0)
--------------------------Neutral(D1024-1)
--------------------------Negative(D1024-2)
---------------------Sound(D1025)
--------------------------Positive(D1025-0)
--------------------------Neutral(D1025-1)
--------------------------Negative(D1025-2)
---------------------Cleanness(D1026)
---------------------Dirtiness(D1027)
---------------------Time_of_a_Day(D1028)
--------------------------Positive(D1028-0)
--------------------------Neutral(D1028-1)
--------------------------Negative(D1028-2)
```

```
---------------------Object_Dumpster_Garbage_Bottle(D1029)
--------------------------Positive(D1029-0)
--------------------------Neutral(D1029-1)
--------------------------Negative(D1029-2)
---------------------Presence_of_Humans(D10210)
--------------------------Positive(D10210-0)
--------------------------Neutral(D10210-1)
--------------------------Negative(D10210-2)
---------------------Implication_of_Humans(D10211)
--------------------------Positive(D10211-0)
--------------------------Neutral(D10211-1)
--------------------------Negative(D10211-2)
---------------------Presence_of_Buildings(D10212)
--------------------------Positive(D10212-0)
--------------------------Neutral(D10212-1)
--------------------------Negative(D10212-2)
---------------------Distance_Time(D10213)
--------------------------Positive(D10213-0)
--------------------------Neutral(D10213-1)
--------------------------Negative(D10213-2)
---------------------No_Presence_of_Humans(D10214)
--------------------------Positive(D10214-0)
--------------------------Neutral(D10214-1)
--------------------------Negative(D10214-2)
---------------------No_Presence_of_Buildings(D10215)
--------------------------Positive(D10215-0)
--------------------------Neutral(D10215-1)
--------------------------Negative(D10215-2)
---------------------I_Can_Handle_Hostile_Humans(D10216)
---------------------I_Cant_Handle_Hostile_Humans(D10217)
---------------------Witness_Help(D10218)
---------------------No_Witness_No_Help(D10219)
---------------------No_Presence_Objects(D10220)
--------------------------Positive(D10220-0)
--------------------------Neutral(D10220-1)
--------------------------Negative(D10220-2)
---------------------Space_Same_Size_Width_Length(D10221)
--------------------------Positive(D10221-0)
--------------------------Neutral(D10221-1)
--------------------------Negative(D10221-2)
---------------------Other(D10222)
----------------Because_of_Neither(D103)
---------------------Virtual_Not_Real(D1030)
---------------------Other(D1031)
-----------Wide(D11)
----------------Because_of_Narrow(D110)
---------------------Safe_Positive_Feeling(D1100)
```

```
--------------------------Physical(D11000)
-------------------------------Prospect(D110000)
-------------------------------Exposure_Low_Concealment(D110001)
-------------------------------Access_Not_Trapped(D110002)
-------------------------------Personal_More_Space(D110003)
-------------------------------Image_Graffiti_Writing(D110004)
-------------------------------Brightness(D110005)
-------------------------------Smell(D110006)
-------------------------------Sound(D110007)
-------------------------------Cleanness(D110008)
-------------------------------Time_of_a_Day(D110009)
-------------------------------Object_Dumpster_Garbage_Bottle(D1100010)
-------------------------------Hidden_Space(D1100011)
-------------------------------No_Presence_of_Objects(D1100012)
-------------------------------Other(D1100013)
--------------------------Social(D11001)
-------------------------------Presence_of_Friendly_Humans(D110010)
-------------------------------Implication_of_Friendly_Humans(D110011)
-------------------------------Presence_of_Friendly_Buildings(D110012)
-------------------------------No_Presence_of_Hostile_Humans(D110013)
-------------------------------No_Presence_of_Hostile_Buildings(D110014)
-------------------------------I_Can_Handle_Hostile_Humans(D110015)
-------------------------------Witness_Help(D110016)
-------------------------------Other(D110017)
--------------------------Other(D11002)
---------------------Fear_Negative_Feeling(D1101)
--------------------------Physical(D11010)
-------------------------------Blocked_Prospect(D110100)
-------------------------------Concealment(D110101)
-------------------------------Entrapment(D110102)
-------------------------------Confined_Less_Space(D110103)6
-------------------------------Image_Graffiti_Writing(D110104)
-------------------------------Darkness(D110105)
-------------------------------Smell(D110106)
-------------------------------Sound(D110107)
-------------------------------Dirtiness(D110108)
-------------------------------Time_of_a_Day(D110109)
-------------------------------Object_Dumpster_Garbage_Bottle(D1101010)
-------------------------------Hidden_Space(D1101011)
-------------------------------No_Presence_of_Objects(D1101012)
-------------------------------Other(D1101013)
--------------------------Social(D11011)
-------------------------------Presence_of_Hostile_Humans(D110110)
-------------------------------Implication_of_Hostile_Humans(D110111)
-------------------------------Presence_of_Hostile_Buildings(D110112)3
-------------------------------No_Presence_of_Friendly_Humans(D110113)
-------------------------------No_Presence_of_Friendly_Buildings(D110114)
```

```
-------------------------------I_Cant_Handle_Hostile_Humans(D110115)
-------------------------------No_Witness_No_Help(D110116)
-------------------------------Other(D110117)
--------------------------Other(D11012)
---------------------Distance_Time(D1102)
--------------------------Long_Far_Slow(D11020)
--------------------------Short_Closer_Fast(D11021)
---------------------Other_Items_Noticed(D1103)
--------------------------Hidden_Space(D11030)
--------------------------Image_Graffit_Writing(D11031)
--------------------------Smell(D11032)
--------------------------Sound(D11033)
--------------------------Time_of_a_Day(D11034)
--------------------------Object_Dumpster_Garbage_Bottle(D11035)
--------------------------Presence_of_Humans(D11036)
--------------------------Implication_of_Humans(D11037)
--------------------------Presence_of_Buildings(D11038)
--------------------------No_Presence_of_Humans(D11039)
--------------------------No_Presence_of_Buildings(D110310)
--------------------------No_Presence_of_Objects(D110311)
--------------------------Other(D110312)
----------------Because_of_Wide(D111)
---------------------Safe_Positive_Feeling(D1110)
--------------------------Physical(D11100)
-------------------------------Prospect(D111000)
-------------------------------Exposure_Low_Concealment(D111001)
-------------------------------Access_Not_Trapped(D111002)
-------------------------------Personal_More_Space(D111003)2
-------------------------------Image_Graffiti_Writing(D111004)
-------------------------------Brightness(D111005)
-------------------------------Smell(D111006)
-------------------------------Sound(D111007)
-------------------------------Cleanness(D111008)
-------------------------------Time_of_a_Day(D111009)
-------------------------------Object_Dumpster_Garbage_Bottle(D1110010)
-------------------------------Hidden_Space(D1110011)
-------------------------------No_Presence_of_Objects(D1110012)
-------------------------------Other(D1110013)
--------------------------Social(D11101)
-------------------------------Presence_of_Friendly_Humans(D111010)
-------------------------------Implication_of_Friendly_Humans(D111011)
-------------------------------Presence_of_Friendly_Buildings(D111012)
-------------------------------No_Presence_of_Hostile_Humans(D111013)
-------------------------------No_Presence_of_Hostile_Buildings(D111014)
-------------------------------I_Can_Handle_Hostile_Humans(D111015)
-------------------------------Witness_Help(D111016)
-------------------------------Other(D111017)
```

```
--------------------------Other(D11102)
---------------------Fear_Negative_Feeling(D1111)
--------------------------Physical(D11110)
-------------------------------Blocked_Prospect(D111100)
-------------------------------Concealment(D111101)
-------------------------------Entrapment(D111102)
-------------------------------Confined_Less_Space(D111103)
-------------------------------Image_Graffiti_Writing(D111104)
-------------------------------Darkness(D111105)
-------------------------------Smell(D111106)
-------------------------------Sound(D111107)
-------------------------------Dirtiness(D111108)
-------------------------------Time_of_a_Day(D111109)
-------------------------------Object_Dumpster_Garbage_Bottle(D1111010)
-------------------------------Hidden_Space(D1111011)
-------------------------------No_Presence_of_Objects(D1111012)
-------------------------------Other(D1111013)
--------------------------Social(D11111)
-------------------------------Presence_of_Hostile_Humans(D111110)
-------------------------------Implication_of_Hostile_Humans(D111111)
-------------------------------Presence_of_Hostile_Buildings(D111112)
-------------------------------No_Presence_of_Friendly_Humans(D111113)
-------------------------------No_Presence_of_Friendly_Buildings(D111114)
-------------------------------I_Cant_Handle_Hostile_Humans(D111115)
-------------------------------No_Witness_No_Help(D111116)
-------------------------------Other(D111117)
--------------------------Other(D11112)
---------------------Distance_Time(D1112)
--------------------------Long_Far_Slow(D11120)
--------------------------Short_Closer_Fast(D11121)
---------------------Other_Items_Noticed(D1113)
--------------------------Hidden_Space(D11130)
--------------------------Image_Graffit_Writing(D11131)
--------------------------Smell(D11132)
--------------------------Sound(D11133)
--------------------------Time_of_a_Day(D11134)
--------------------------Object_Dumpster_Garbage_Bottle(D11135)
--------------------------Presence_of_Humans(D11136)
--------------------------Implication_of_Humans(D11137)
--------------------------Presence_of_Buildings(D11138)
--------------------------No_Presence_of_Humans(D11139)
--------------------------No_Presence_of_Buildings(D111310)
--------------------------No_Presence_of_Objects(D111311)
--------------------------Other(D111312)
----------------Because_of_Both_Items_Noticed(D112)
---------------------Hidden_Space(D1120)
--------------------------Positive(D1120-0)
```

```
--------------------------Neutral(D1120-1)
--------------------------Negative(D1120-2)
---------------------Image_Graffiti_Writing(D1121)
--------------------------Positive(D1121-0)
--------------------------Neutral(D1121-1)
--------------------------Negative(D1121-2)
---------------------Brightness(D1122)
---------------------Darkness(D1123)
---------------------Smell(D1124)
--------------------------Positive(D1124-0)
--------------------------Neutral(D1124-1)
--------------------------Negative(D1124-2)
---------------------Sound(D1125)
--------------------------Positive(D1125-0)
--------------------------Neutral(D1125-1)
--------------------------Negative(D1125-2)
---------------------Cleanness(D1126)
---------------------Dirtiness(D1127)
---------------------Time_of_a_Day(D1128)
--------------------------Positive(D1128-0)
--------------------------Neutral(D1128-1)
--------------------------Negative(D1128-2)
---------------------Object_Dumpster_Garbage_Bottle(D1129)
--------------------------Positive(D1129-0)
--------------------------Neutral(D1129-1)
--------------------------Negative(D1129-2)
---------------------Presence_of_Humans(D11210)
--------------------------Positive(D11210-0)
--------------------------Neutral(D11210-1)
--------------------------Negative(D11210-2)
---------------------Implication_of_Humans(D11211)
--------------------------Positive(D11211-0)
--------------------------Neutral(D11211-1)
--------------------------Negative(D11211-2)
---------------------Presence_of_Buildings(D11212)
--------------------------Positive(D11212-0)
--------------------------Neutral(D11212-1)
--------------------------Negative(D11212-2)
---------------------Distance_Time(D11213)
--------------------------Positive(D11213-0)
--------------------------Neutral(D11213-1)
--------------------------Negative(D11213-2)
---------------------No_Presence_of_Humans(D11214)
--------------------------Positive(D11214-0)
--------------------------Neutral(D11214-1)
--------------------------Negative(D11214-2)
---------------------No_Presence_of_Buildings(D11215)
```

```
--------------------------Positive(D11215-0)
--------------------------Neutral(D11215-1)
--------------------------Negative(D11215-2)
---------------------I_Can_Handle_Hostile_Humans(D11216)
---------------------I_Cant_Handle_Hostile_Humans(D11217)
---------------------Witness_Help(D11218)
---------------------No_Witness_No_Help(D11219)
---------------------No_Presence_Objects(D11220)
--------------------------Positive(D11220-0)
--------------------------Neutral(D11220-1)
--------------------------Negative(D11220-2)
---------------------Space_Same_Size_Width_Length(D11221)
--------------------------Positive(D11221-0)
--------------------------Neutral(D11221-1)
--------------------------Negative(D11221-2)
---------------------Other(D11222)
----------------Because_of_Neither(D113)
---------------------Virtual_Not_Real(D1130)
---------------------Other(D1131)
```

Appendix C

Consent Form

Form 2- Informed Consent By Participants In a Research Study

The University and those conducting this research study subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of participants. This research is being conducted under permission of the Simon Fraser Research Ethics Board. The chief concern of the Board is for the health, safety and psychological well-being of research participants.

Should you wish to obtain information about your rights as a participant in research, or about the responsibilities of researchers, or if you have any questions, concerns or complaints about the manner in which you were treated in this study, please contact the Director, Office of Research Ethics by email at hweinber@sfu.ca or phone at 778-782-6593.
Your signature on this form will signify that you have received a document which describes the procedures, whether there are possible risks, and benefits of this research study, that you have received an adequate opportunity to consider the information in the documents describing the study, and that you voluntarily agree to participate in the study.

Title: Investigating Factors that Influence Pedestrian Navigation*

Investigator Name: Andrew Park

Investigator Department: School of Interactive Arts and Technology

---

*The actual title is not given at this point for the purpose of this experiment.

Having been asked to participate in a research project or experiment, I certify that I have read the procedures specified in the Study Information Document describing the study. I understand the procedures to be used in this study and the personal risks to me in taking part in the study as described below:

Purpose and goals of this study:

This study is designed to investigate factors that influence pedestrian navigation. Research related to this topic has been done qualitatively such as using photographs or visiting certain sites (usually within a campus). Our study is examining a new way of studying in this field by using a 3D virtual reality (VR) model of an urban environment. The result of this study will also be used to evaluate and validate the computational model of a pedestrian that we have developed.

What the participants will be required to do:

You will have a chance to read the consent form and decide whether you will participate in the experiment. If you agree to participate in the experiment and sign the consent form, you will be asked to complete a background questionnaire. Then you will stand or sit in front of a large projector screen. You will have a short practice session to learn how to navigate the virtual urban environment using a remote controller. After the practice session, you will receive instructions about the task that you will perform during the experiment session. When the experiment starts, you will navigate the virtual urban environment from the starting position to the destination. While navigating, you will reach several decision points. At each decision point, you will choose one of the two routes according to your judgment. When you reach the destination, the experiment session is over. Then the investigator will have an interview with you, watching the recorded screen replaying. The experiment session and the interview session will be recorded with a video camera. During the experiment session, your skin conductance will be measured using biofeedback equipment provided by Thought Technologies Inc. This gives us a measure of how you are feeling. You will take an exit questionnaire for the purpose of evaluating and improving the experiment.

Risks to the participant, third parties or society:

The biofeedback equipment that we are going to use is a battery operated device. There is no known risk in using this device. Some of the potential risks involved with this study are: -The participant might experience dizziness while he/she navigates in the 3D VR environment. -The participant might experience a short-term feeling of uneasiness due to some of the situations he/she faces during the navigation. However, this is not more than watching a suspenseful TV show or playing a teen video game and we don't think it would have a long-term psychological affect at all.

Benefits of study to the development of new knowledge:

The benefits of this study are: The developed VR urban model can be used as an experimental tool for research in urban planning and other fields. The developed simulation system with the pedestrian model can be used for urban planners to test their new designed layouts for buildings and parks.

Statement of confidentiality: The data of this study will maintain confidentiality of your name and the contributions you have made to the extent allowed by the law.

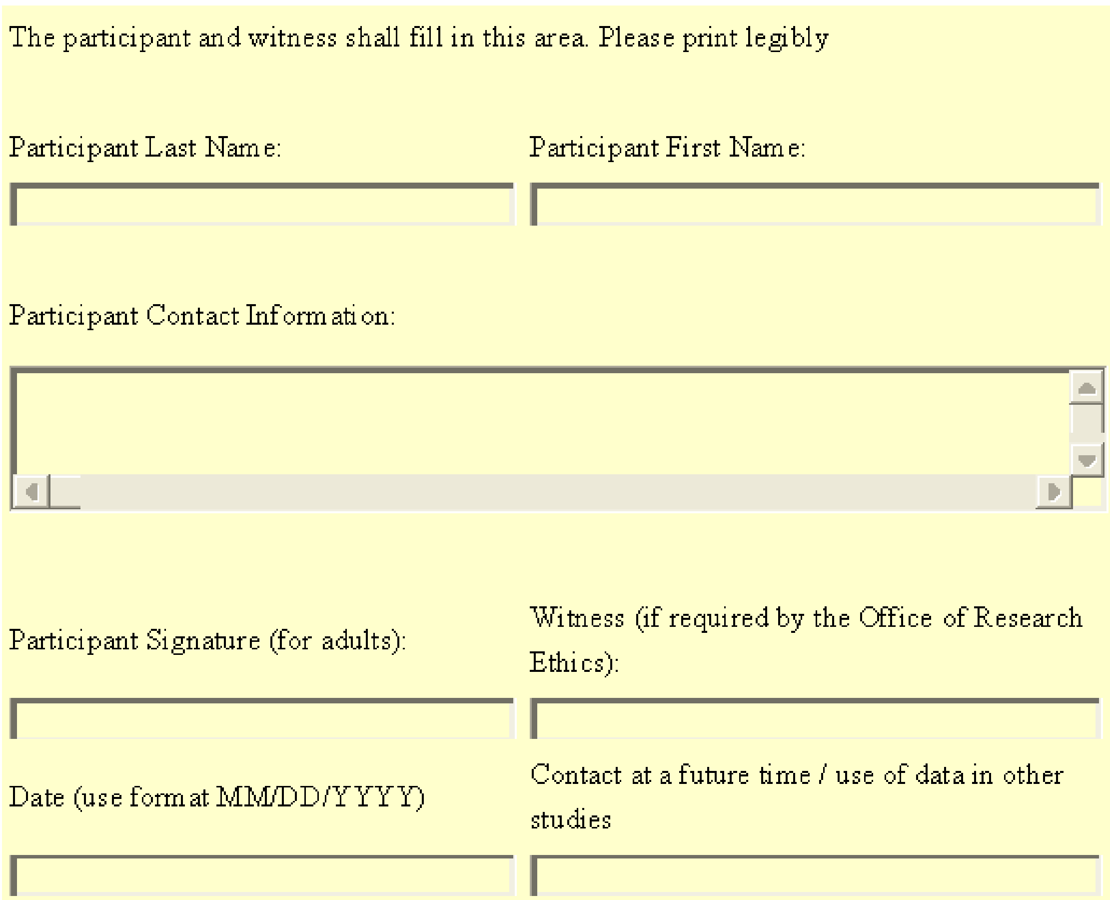
I understand that I may withdraw my participation at any time. I also understand that I may register any complaint with the Director of the Office of Research Ethics.

Director, Office of Research Ethics 8888 University Drive Simon Fraser University Burnaby, British Columbia Canada V5A 1S6 +1 778 782 3447 email: dore@sfu.ca

I may obtain copies of the results of this study, upon its completion by contacting:

Andrew Park (aparkd@sfu.ca)

I understand the risks and contributions of my participation in this study and agree to participate:


The participant and witness shall fill in this area. Please print legibly

Participant Last Name:

Participant First Name:

Participant Contact Information:

Participant Signature (for adults):

Witness (if required by the Office of Research Ethics):

Date (use format MM/DD/YYYY)

Contact at a future time / use of data in other studies

Appendix D

Questionnaires

The questionnaires that are shown here were used for our experiments with human subjects. The consent form also is included here.

D.1 Background Questionnaire

Simon Fraser University
School of Interactive Arts and Technology
Pedestrian Navigation Study

The responses provided here will be held in strict confidence.

Background Questionnaire **Subject#:**____________

Please write an answer or circle one of choices for each question.

1. What is your age?

(a) 19 - 29
(b) 30 - 39
(c) 40 - 49
(d) 50 - 59
(e) 60 or older

2. What is your gender?

(a) Male

(b) Female

3. What is your ethnicity?

(a) Asian

(b) Black

(c) Caucasian/White

(d) Hispanic

(e) Indigenous or Aboriginal

(f) Other:____________________________

4. What is your marital status?

(a) Married

(b) Living common-law

(c) Widowed

(d) Separated

(e) Divorced

(f) Single, never married

5. What is the highest level of education you have completed?

(a) Grammar school

(b) High school or equivalent

(c) Post-secondary school (2-year college, university, or graduate school)

(d) Other:____________________________

6. Which of the following best describes the area you live in?

(a) Urban(City)

(b) Rural(Country)

(c) Don't know

7. Where do you live?

(a) Abbotsford

(b) Burnaby
(c) Coquitlam
(d) Delta
(e) Langley
(f) New Westminster
(g) Richmond
(h) Surrey
(i) Vancouver
(j) North Vancouver
(k) Other:____________________________

8. How many family members live in your household? ______________________

9. What is your family's annual income in Canadian dollars?

(a) Under $10,000
(b) $10,000 - $19,999
(c) $20,000 - $29,999
(d) $30,000 - $39,999
(e) $40,000 - $49,999
(f) $50,000 - $59,999
(g) ABove $60,000
(h) Would rather not say

10. Which of the following best describes your occupation?

(a) Homemaker
(b) Retired
(c) Student
(d) Self-employed
(e) Employed
(f) Other:____________________________

D.2 Exit Questionnaire

Simon Fraser University
School of Interactive Arts and Technology
Pedestrian Navigation Study

The responses provided here will be held in strict confidence.

Exit Questionnaire **Subject#:**_____________

Please circle one of choices for each question.

1. How long have you lived in the Lower Mainland area (the greater Vancouver area)?

(a) Never
(b) Less than 1 year
(c) 1 to 2 years
(d) More than 2 years

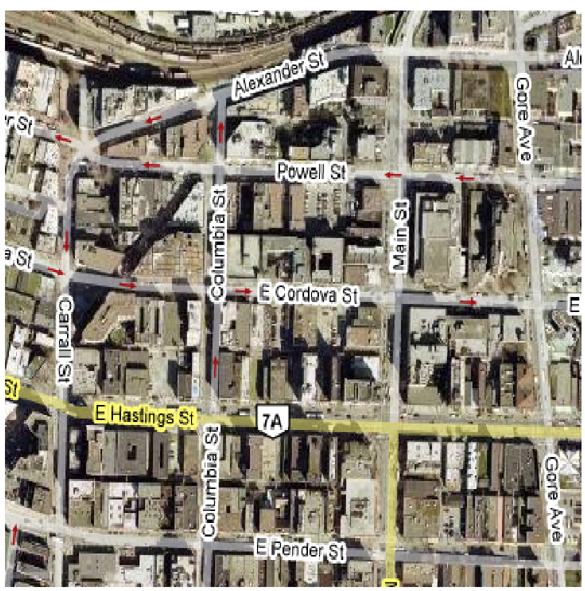


Figure D.1: The Downtown Eastside of Vancouver

Note: For Questions 2-6, refer to the map on mage 1.

2. How often have you walked in the Downtown Eastside of Vancouver in the last 5 years?

(a) Never
(b) Once
(c) Twice
(d) More than twice

3. If you have walked in the Downtown Eastside of Vancouver in the last 5 years, while walking did you feel:

(a) very safe
(b) reasonably safe
(c) somewhat unsafe
(d) very unsafe

4. Would you say Surrey has a high crime problem?

(a) Yes
(b) No

5. Compared to Surrey, do you think the Downtown Eastside of Vancouver has a higher amount of crime, about the same or a lower amount of crime?

(a) Higher
(b) About the same
(c) Lower
(d) Don't know

6. During the last 5 years, do you think that crime in the Downtown Eastside of Vancouver has increased, decreased, or remained about the same?

(a) Increased
(b) Decreased
(c) About the same
(d) Don't know

7. Would you walk alone in the area of your home after dark (i.e. around the block)?

(a) Yes

(b) No

8. If no (in Question 7), why do you not walk alone after dark? Because you feel:

(a) somewhat unsafe

(b) very unsafe

(c) have some other reason

9. Have you waited for public transportation alone after dark?

(a) Yes

(b) No

10. If yes (in Question 9), while waiting for or using public transportation alone after dark, do you feel:

(a) very worried about your safety from crime

(b) somewhat worried about your safety from crime

(c) not at all worried about your safety from crime

(d) do not use public transportation at night

11. When alone in your home in the evening or at night, do you feel:

(a) very worried about your safety from crime

(b) somewhat worried about your safety from crime

(c) not at all worried about your safety from crime

(d) never alone

12. In the past, have you experienced any street crime (i.e. robbery(mugging), snatch theft,) targeted on yourself or seen such crime targeted on others?

(a) Yes

(b) No

13. Have you ever done any of the following things to protect yourself or your property from crime? Have you ever:
... changed your routine, activities, or avoided certain places?

(a) Yes

(b) No

14. Do you do any of the following things to make yourself safer from crime? Do you routinely:
... carry something (i.e. a whistle, personal alarms, pepper spray) to defend yourself or to alert other people?

(a) Yes

(b) No

15. Do you do any of the following things to make yourself safer from crime? Do you routinely:
... plan your route with safety in mind?

(a) Yes

(b) No

16. Do you do any of the following things to make yourself safer from crime? Do you routinely:
... stay at home at night because you are afraid to go out alone

(a) Yes

(b) No

17. In general, how satisfied are you with the steps you take to ensure your personal safety from crime. Are you:

(a) very satisfied

(b) somewhat satisfied

(c) somewhat dissatisfied

(d) very dissatisfied?

18. Would you describe yourself as:

(a) bold

(b) fearful

(c) average

Please circle one of the choices for each question.

1. I often play video games.

1———2———3———4———5———6———7

definitely true — definitely untrue

2. I felt as if I was playing a video game during the navigation.

1———2———3———4———5———6———7

definitely true — definitely untrue

3. I navigated in the virtual urban environment as if I was navigating in the real urban environment.

1———2———3———4———5———6———7

definitely true — definitely untrue

4. It was easy to learn how to navigate through the virtual urban environment.

1———2———3———4———5———6———7

definitely true — definitely untrue

5. In this experiment I felt under pressure to complete the navigation using the shortest path.

1———2———3———4———5———6———7

definitely true | definitely untrue

6. Moving in the virtual environment made me feel dizzy.

1———2———3———4———5———6———7

definitely true | definitely untrue

7. I was often disoriented in navigating through the virtual urban environment.

1———2———3———4———5———6———7

definitely true | definitely untrue

8. I felt uneasiness, discomfort or some emotional disturbance when I confronted certain situations during the navigation.

1———2———3———4———5———6———7

definitely true | definitely untrue

* If you would like to leave your comments or share your experiences regarding this experiment, please write below:

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