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Human Movement and Behaviour Simulation Using Gaming Software

by

Shahrol Mohamaddan

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Abstract

The provision of urban transportation systems that are ‘inclusive’ and allow full participation in society for older people and people with disabilities is an important aspect of urban sustainability. This includes improving the design of transportation interchanges where diverse individual humans interact in a crowded area. Simulation is an example of a beneficial method that can be widely applied to visualise and understand the problems using virtual environments.

This research focuses on the development of simulation tools to simulate human movement and behaviour in crowded areas. A video observational method was applied as an input to understand and analyse human movement and behaviour in the real world. Six hours of video recording were recorded at a multi-mode transportation system covering weekdays, weekend, peak and off-peak times. Almost 19,000 individual humans were observed and the behaviour that they exhibited can be divided into six different types (known as Moving Through, Move-Stop-Move, Queuing, Competitive, Avoiding and Passing Through) which were determined from three major human movement types of free, same and opposite direction.

Object-oriented gaming software was used to simulate the human movement and behaviour in the virtual environment based on agent-based modelling. Six factors affecting human movement and behaviour in the real world including Personal Objective, Visual Perception, Speed of Movement, Personal Space, Crowd Density and Avoidance Angle or Distance were considered as the parameters for the virtual humans. Case studies considering free, same and opposite direction movement with multi-mode transportation systems, bottleneck and non-bottleneck situations were applied to validate the prototype software system.

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Chapter 1: Introduction

A crowd can be defined as a situation where humans flock together like other aggregations of animals (e.g. herds of cattle and schools of fish) or material (e.g. fluid and particle flow) (Henein et al. 2007). A crowd can also be defined as a large group of individuals in the same physical environment and sharing a common goal (Musse et al. 1997). Crowds can occur in many places including for example train stations, shopping malls and stadia. Figure 1.1 shows an example of a crowded situations at a train station, where the humans in the crowd are performing several different types of activity such as queuing up to buy a ticket, chatting to each other, waiting for the train, etc.



Figure 1.1 Crowded situation at a train station

Crowds are an important consideration when people with different abilities and capabilities are journeying from one place to another. Human movement and behaviour in crowds can be considered as random, complex and sometimes unpredictable. Many researchers have published work related to human movement and behaviour in crowds where the focus is more on the emergency evacuation situation. Crowd safety has always been a major concern of this kind of

research and in general the three main objectives are to avoid the occurrence of dangerous crowd phenomena (e.g. fire hazards, accidents, earthquakes, etc.), to reduce the numbers of people injured or killed should it occur and to improve the environment for the crowd in terms of the quality of the facilities, signage and communications. The crowd dynamics research by Still (2000) is a typical example of this area. However, the main focus of this research is the movement and behaviour of individual human beings in normal crowded situations (where no panic situation is involved), and the focus is on the interactions between individuals in localized areas.

An emphasis is placed on gaining knowledge of some of the characteristics of human movement and behaviour in the real world so that these can be modelled in the virtual environment. There are many significant issues related to crowds that can be considered such as how humans move and behave within high density crowds. Do they tolerate or ignore each other during the movement, or do they move more slowly than they would in a low density crowd? If the focus is more towards the older and those with disabilities, there are significant issues such as how an elderly man might maintain his balance and choose his movement direction when people around move at a faster speed or how a disabled person with a wheelchair reacts when faced with a movement path containing obstacles (or bottlenecks). In order to understand those issues, direct observation from the real world crowd is important in order to gather information on the difficulties that they are facing and to investigate what are the factors affecting the movement and behaviour to minimize these difficulties.

This research has its origins in the AUNT-SUE (Accessibility and Users Needs in Transport - Sustainable Urban Environments) project which emphasized the need to accommodate the largest possible range of humans with diverse abilities and aspirations (Marshall et al. 2008). The project was of crucial importance in developing sustainable policies that deliver effective and socially inclusive design in urban transportation systems (Marshall et al. 2005). The AUNT-SUE research did not explicitly consider the issues of human movement and behaviour in crowded areas which is the focus of the research described in this thesis.

1.1 Aim and Objectives

This research is aimed at developing a prototype of a ‘toolkit’ or computer program that is able to simulate human movement and behaviour in crowded areas. The computer program has been developed in the virtual environment based on the understanding of human movement and behaviour in the real world. Based on the philosophy of ‘design for all’ or ‘universal design’, older people and those with disabilities are considered within the simulation together with able-bodied adults¹. This research focuses on how older people, those with disabilities and adults deal with crowded areas during journeys from one place to another.

This research benefits two main areas of research which are ergonomics (or human factors) and transportation. Ergonomics is defined as *the scientific discipline concerned with the understanding of interactions among humans and other elements of a system and to design in order to optimize human well-being and overall system performance* (Thatcher 2013). In ergonomics, this research provides an understanding of human movement and behaviour in crowded areas based on a direct observation technique. In transportation research, the prototype of a computer program has been developed to assist in the analysis of transportation infrastructure building and the effects on humans before the real design is constructed. The research work can also provide a stepping-stone for future research related to facilities design related to human surroundings such as workplaces, road infrastructure, etc.

¹ The language used in this field is very sensitive and liable to misinterpretation. The term ‘older people’ is used in preference to the ‘elderly’ as it is a relative rather than absolute term and better reflects the wide range of ages described by the term. ‘Disabled’ is an unfavoured term as it implies that the person is characterised by their disabilities rather than their abilities. The term to be used is ‘people with disabilities’ as this recognises the disability without implying complete disability. ‘Able-bodied’ is used to describe people who do not have any significant disabilities.

The objectives of the research are as follows:

1. *To study and identify human movement and behaviour in crowded areas to include older people and those with disabilities.*
2. *To develop a framework for the capture and analysis of observational data concerning human movement and behaviour.*
3. *To develop a model of human movement and behaviour in crowded areas.*
4. *To simulate human movement and behaviour using object-oriented methods found in gaming software.*
5. *To verify and validate the effectiveness of the model and simulation program through case studies.*

1.2 Problem Statement and Research Gap

As with the original AUNT-SUE project, this research is mainly concerned with human movement and behaviour in crowded areas during journeys from one point of interest to another. The emphasis is on normal (non-emergency) situations and the interaction between individual humans within localised crowded areas. The inclusion of older people and those with disabilities together with able-bodied adults are the focus of this research. However, literature that focuses on the older people and those with disabilities in the context of crowd research is rather limited.

Brunnhuber et al. (2010) commented that crowd research is still inadequate to represent the mobility needs of older people and those with disabilities. The available simulation software simply represents older people and those with disabilities with lower maximum speed and larger personal space, despite the fact that there might be other factors affecting human movement and behaviour in the real world that could be considered. In order to close this gap there is a need to develop more realistic simulations that are able to differentiate between different subjects with different parameters.

In addition, the available crowd simulation software has been developed based on the developer's point of view without any input from research on, for example, human movement and behaviour from real world observation. Therefore, there is a need to develop a strategy that can understand and reflect the real movement and behaviour of humans. The understanding of the real movement and behaviour at an early stage of computer program development is important to develop reliable software whilst at the same time developing an empathy especially with older people and people with disabilities (Porter et al. 2004).

Finally, a useful case study should be developed as an application of the developed computer program. Besides simulating the real world situation, the case studies can be developed to predict different scenarios and to test different facilities design in the virtual environment. By doing this, the computer program can be beneficial in providing a 'tool' for simulation. In this context simulation using the object-oriented methods found in gaming software is considered a contemporary technique where interactive three dimensional (3D) simulations with different images can be developed at low development cost.

1.3 Scope of the Research

The research was limited to studying human movement and behaviour in normal (non-emergency) situations using video observation conducted at Stesen Sentral Kuala Lumpur, Malaysia, a multi-mode transportation centre. The video observational method was developed to understand human movement and behaviour and was focused on the three major movements of free, same and opposite direction. The research focused on six different behaviours derived from the three movements, namely the Moving Through, Move-Stop-Move, Queuing, Competitive, Avoiding and Passing Through behaviours.

The research was also limited to six different factors affecting human movement and behaviour analysed using the video observational method. The factors were Personal Objective, Visual Perception, Speed of Movement, Personal Space, Crowd Density and Avoidance Angle or Distance. The simulation in the virtual environment was conducted and the factors affecting human movement and behaviour were applied as the parameters for the virtual humans. The simulation focused on two types of simulation, namely the empty and building design.

The empty design covers the simulation in free, same and opposite direction movement where the objective is to confirm that the modelling of individual behaviours in the virtual environment has some kind of agreement with the real world. On the other hand, the building design that consists of simulation of a multi-mode transportation system, bottleneck and non-bottleneck layouts is conducted with the objective to show the effectiveness and usefulness of the simulation software.

1.4 Research Methodology

The research was conducted based on the research methodology framework shown in Figure 1.2.

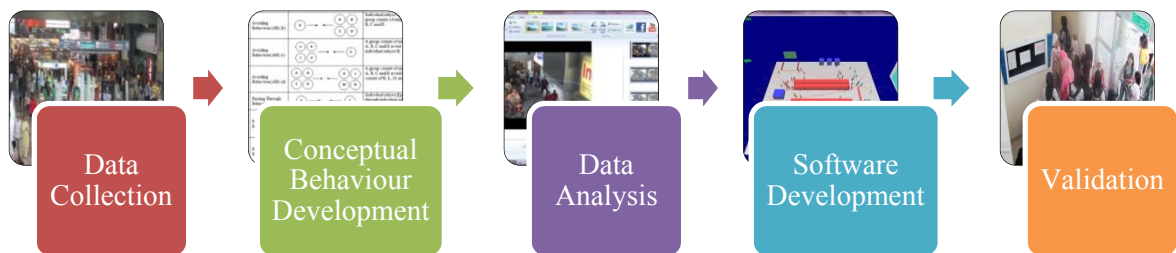


Figure 1.2 Research methodology framework

1.4.1 Data Collection

Data collection was the first step conducted in the research. It is the process of recording human movement and behaviour in the real world. An appropriate location was selected in order to reflect the research objective. A detailed discussion of the data collection is given in Section 4.2 of the thesis.

1.4.2 Conceptual Behaviour Development

Conceptual behaviour development refers to the process of developing a set of rules from the understanding of human movement and behaviour as recorded in the real world. The conceptual behaviours become a source of reference to assist in the data analysis. A detailed discussion of the conceptual behaviour development is provided in Section 4.3 of the thesis.

1.4.3 Data Analysis

Data analysis was undertaken to analyse the human movement and behaviour recorded on video. The process focused on the number of individual humans involved and the factors affecting the movement and behaviour. The conceptual behaviours were used in document form as a source of reference during the analysis. In addition, observational supporting software was introduced to assist the analysis and an observational database was developed to record the results of the observational analysis. A detailed discussion of the data analysis is to be found in Section 4.4.

1.4.4 Software Development

Software development refers to the process of transferring the understanding (or knowledge) of human movement and behaviour gained from the observational analysis in the real world into a virtual environment. During this process, some modifications were made to the movement and behaviour in the real world to adapt it to the limitations of the software. A detailed discussion on the software development is conducted in Chapter 6.

1.4.5 Validation

Validation was the final process involved in the research. Two types of validation were carried out: software validation and case studies. In software validation, simple simulations were created to confirm that the individual movements and behaviours in the virtual environment had some kind of agreement with those in the real world. In the case studies different types of building layout were selected and simulated to show the effectiveness and usefulness of the method. The

case studies were also compared qualitatively with other real world building layouts to show the impact of the simulation. A detailed discussion on the validation is conducted in Chapter 7.

1.5 Thesis Structure

The thesis consists of eight chapters including this introductory chapter. The contents of the chapters are as follows:

Chapter 2: Review of Crowd Research

This chapter consists of the literature review focused on crowd research which consists of the three major areas of crowd monitoring, experimental studies with crowds and crowd modelling and simulation. This chapter concludes by differentiating the crowd modelling and simulation into three different features that indicate the research focus. These are character, scale and situation.

Chapter 3: Review of Human Behaviour in Crowds and the Application of Gaming Software

This chapter reviews human behaviour in crowds and provides examples of human behaviours that have been applied in crowd research. This chapter also presents the requirements for software simulation selection and introduces the DarkBASIC Professional gaming software used for the research. Example of applications developed using the software are also discussed.

Chapter 4: Video Observational Studies

This chapter discusses the video observational method developed for this research. The video observational method is used to understand human movement and behaviour in the real world. Video observational software is applied and an observational database is developed to assist the analysis process. The discussion also includes the selection of the human movements and behaviours for the research based on the observational process.

Chapter 5: Video Observational Results and Discussion

This chapter discusses the results and analysis of the video observational process conducted in Chapter 4. The chapter shows different factors affecting human movement and behaviour in crowded areas based on the analysis using video observational method. The analysis conducted is used as an insight into developing human simulation in a virtual environment.

Chapter 6: Software Design and Modelling

This chapter discusses the process involved in applying the DarkBASIC Professional gaming software as a tool to simulate human movement and behaviour in a virtual environment. The main discussion is on the process to transfer the human movement and behaviour from the real world to the virtual environment.

Chapter 7: Software Validation and Case Studies

This chapter shows the evaluation process conducted using the gaming software for the simulation of empty and building design. In total six different simulations were conducted including free, same and opposite directions with the multi-mode transportation system, bottleneck and non-bottleneck layouts. The results and discussion of the simulations conducted provide an insight into the ability of the software to confirm individual behaviour similar to real world behaviour and shows its effectiveness and usefulness.

Chapter 8: Conclusion and Future Work

This chapter provides a conclusion for the research including the contribution made to knowledge. Further opportunities originating from this research work are also discussed.

Chapter 2: Review of Crowd Research

This chapter provides an overview of crowd research from selected areas, namely crowd monitoring, experimental studies with crowds and crowd modelling and simulation. Several applications from each research area have been selected for discussion. The understanding of crowd research is an important input for this research to ensure that the application, selection and refinement of the methods are supported by sufficient arguments.

2.1 Introduction

The importance and potential of crowds discussed in the previous chapter have encouraged researchers from different aspects of research such as engineering, psychology and ergonomics to conduct crowd research so as to gain better understanding of the human behaviour involved. In general, crowd research can be divided into three major areas, namely crowd monitoring, experimental studies with crowds and crowd modelling and simulation as shown in Figure 2.1. Each research area attempts to understand the issues from different views and approaches.

Crowd monitoring is focused on automated systems developed to observe crowds. Three example applications have been selected for discussion and these are density estimation, movement tracking and behaviour observation. The experimental studies with crowds are focused on laboratory experiments and the two examples of bottleneck design and evacuation flow have been selected for discussion.

Finally, crowd modelling and simulation is focused on different types of model developed for crowds or individual humans in a crowd. Crowd modelling and simulation is considered as a major focus areas for crowd research and is the focus area of this research. Four models have been selected for discussion and these are cellular automata, social force, lattice gas and agent-based. The discussion is conducted in order to obtain an overview of the models and to differentiate the focus areas based on the selected features of character, scale and situation.

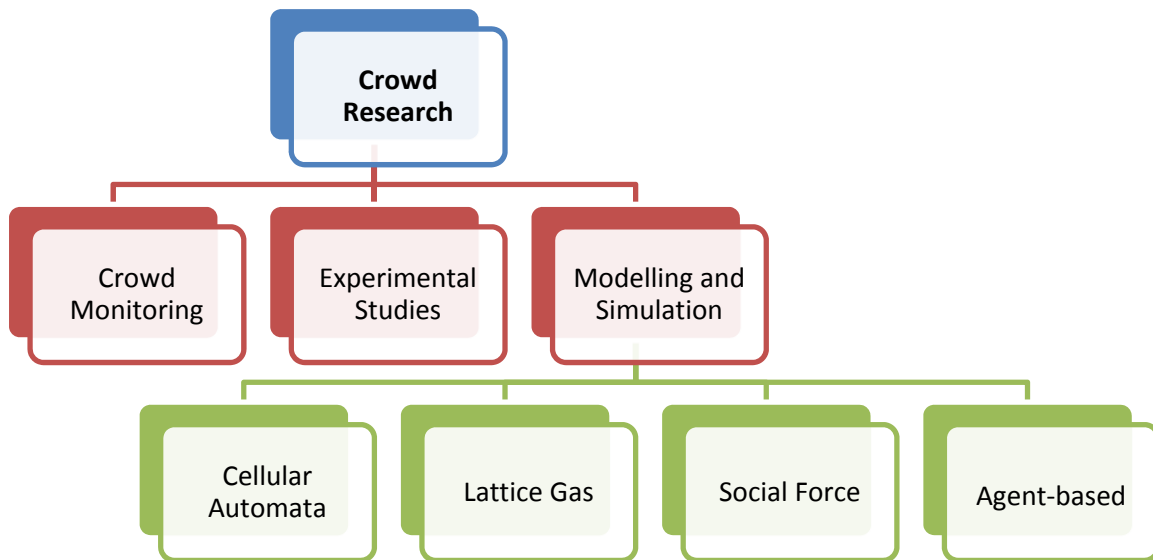


Figure 2.1 Overview of crowd research

2.2 Crowd Monitoring

Crowd monitoring research focuses on the development of automated monitoring systems using computer vision to monitor crowd safety. The automated monitoring system is developed as human observers are unable to monitor numerous screens simultaneously when using Closed Circuit Television (CCTV). Crowd monitoring systems provide automatic systems that can be applied in various situations, but there are still several conditions that limit their effectiveness.

One of the disadvantages of crowd monitoring using computer systems is the difficulty in operating the system if there are a large number of moving objects within the video data. Computer vision is also very sensitive to lighting and variation of illumination caused by aspects such as the weather, clothes and floor texture. Tracking humans in an outdoor scene is very complex since the number of humans and vehicles are unpredictable at any one time. The computer vision systems need more processing power when there is a high density of humans. In this section crowd monitoring is discussed using three example applications which are crowd density estimation, movement tracking and behaviour observation.

2.2.1 Crowd Density Estimation

Crowd density estimation is used to develop and maintain crowd safety by identifying areas where crowds are building up. The area where the crowd is likely to build up should be identified prior to the event or operation of the venue. Areas where people are likely to congregate need careful observation to ensure crowd safety, management and control. Rahmalan et al. (2006), Yin et al. (1996) and Davies et al. (1995) applied computer vision to estimate crowd density. Pixel data from the video images was used to classify the pedestrians in the crowd; increased numbers of pixels represents an increase in the number of pedestrians. According to Rahmalan et al. (2006)

there are two ways to estimate crowd density; firstly by providing an approximate number of how many people are in the target area and secondly by providing a range of people in the crowd by determining the density in broad classes such as low, medium and high densities.

2.2.2 Crowd Movement Tracking

Crowd movement tracking is developed to track human movement in a crowded area. For example Maurin et al. (2002) applied a vision system to monitor crowded traffic that consisted of humans and vehicles. The research was used to develop an automatic walk signal request for pedestrians, to study the flow pattern at road intersections for city planning and to monitor crowd density at locations where there are often accidents. Tung et al. (2011) applied intelligent goal-based vision trajectory as a surveillance system to automate the monitoring of unusual events and to alert human operators when unusual events or human behaviour is detected. Syed Shazali et al. (2011) developed a method to calculate the speed of human movement in an outdoor area and applied the knowledge in human movement simulation as shown in Figure 2.2.



Figure 2.2 *Tracking human movement in an outdoor area* (Syed Shazali et al. 2011)

2.2.3 Crowd Behaviour Observation and Analysis

Crowd behaviour observation is used to study human movement and behaviour in crowds. Crowd behaviour analysis using computer vision is a new area of interest in the research community (Mehran et al. 2009). Hoogendoorn et al. (2003) applied image processing methods in crowd experimental studies to gain more insight into microscopic pedestrian behaviour and flow characteristics. The pedestrians wore different coloured caps to differentiate their movement and behaviour as shown in Figure 2.3.

Andrade et al. (2006) applied computer vision to detect events within video data. A training model consisting of a set of behaviours was developed and was compared with the video data to detect related events. Mehran et al. (2009) developed a method to detect and localize abnormal behaviours in crowd videos using a Social Force model. The human activity in crowds was detected from the motion of movement in video frames (optical flow technique). The method was tested using a dataset of crowd videos including normal and abnormal (e.g. escape, panic) scenarios.



Figure 2.3 *Example of crowd behaviour observation* (Hoogendoorn et al. 2003)

2.3 Experimental Studies with Crowds

Experimental studies with crowds and individuals in a crowd use a laboratory setup with real humans to analyse movement and behaviour. Video cameras are used to record human movement within the built-up environment based on the objective of the experiment. The advantage of using experimental methods is that human movement can be easily monitored and controlled by the researchers. Experimental studies can also avoid issues of privacy and safety when dealing with real environments, especially when the conditions to be observed are either not available or very difficult (Hoogendoorn et al. 2005). Experimental studies also allow the causes and relationships that determine human behaviour to be observed and provide real data that can be used to evaluate simulation techniques.

Although experimental studies can provide better understanding of crowds, there are several criticisms regarding the method. Seyfried et al. (2009) commented that incentives given to the participants can influence their psychological state. Also, different conditions affect real world movement and behaviour and for example crowds of commuters will behave differently from crowds at a shopping complex. These conditions cannot be observed within the laboratory setup. Lastly, Gwynne et al. (1999) commented that experimental studies pose ethical, practical and financial problems especially related to real world evacuation demonstrations (emergency situations). In this section research concerned with experimental studies is discussed using two example applications; bottleneck design and evacuation flow.

2.3.1 Bottleneck Design

Kretz et al. (2006b) refer to a bottleneck as being a limited area of reduced capacity or increased demand. Bottlenecks can be found in many places in building layouts. Figure 2.4 shows

an example of bottlenecks in a lecture hall and office area at a university in Malaysia. The image shows that a jam at the bottleneck occurs when the incoming flow exceeds the capacity of the bottleneck (Figure 2.4 (a)). Bottlenecks also affect human speed of movement since humans have to adjust their movement due to the size of the bottleneck (Figure 2.4 (b)).



Figure 2.4 Example of bottleneck layout at the lecture hall and office area

Bottleneck experiments are conducted to gain an insight into human behaviour so that tools can be developed to predict behaviour. The understanding of human behaviour for tool development is essential for the public pedestrian facilities planning and designing public areas such as airports, transfer stations and shopping malls (Hoogendoorn et al. 2005). Kretz et al. (2006a, 2006b) and Seyfried et al. (2009) used experimental studies to update handbooks or planning guidelines for capacity estimation of openings, doors and bottlenecks such as the handbook of the Society of Fire Protection Engineers (SFPE).

Figure 2.5 shows an example of a crowd experiment conducted to evaluate the effect of bottlenecks on the crowd. In the research, different researchers used different bottleneck layouts to evaluate the effects on crowds. The differences observed were the geometry of the bottleneck (the length and position of the incoming flow) and the initial condition of the humans (initial density value and initial distance between the human and the bottleneck). The experimental results showed

that during entry to the bottleneck a self-organization phenomenon called the zipper effect occurred and this optimized the available space and velocity inside the bottleneck.

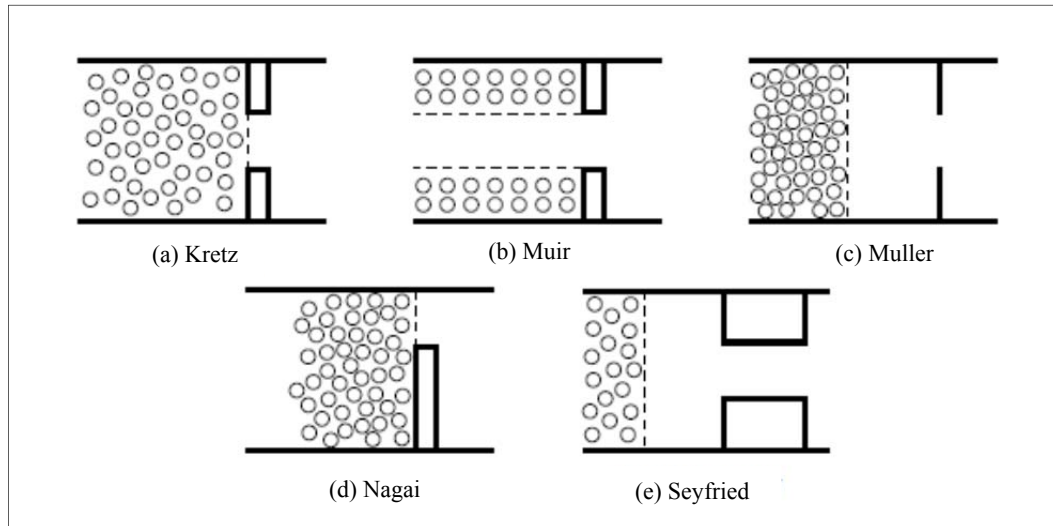


Figure 2.5 Example of crowd experiment layouts by different researchers (Seyfried et al. 2009)

2.3.2 Evacuation Flow

Evacuation flow refers to the evacuation process during emergency situations that occurs in a crowded area. Shimada et al. (2006) conducted an experiment to study the characteristics of crowd evacuation flow with wheelchair users as shown in Figure 2.6. The experimental setup used a temporary construction consisting of flooring, a plywood panel for the door and a camera and light at the entrance to record the evacuation flow.

The experiment was conducted within the experimental area where the effect on evacuation of wheelchair users with assistants and without assistants was monitored. The experiment was conducted with different crowd densities, different size of door opening and mixed numbers of wheelchair users. The experiment indicated that humans twisted their body to pass through the small entrance during the evacuation. When the crowd consisted of the wheelchair users, humans

were observed to stop at the rear and both side of the wheelchair and the movement flow was divided into parts. The flow of the wheelchair users without assistants (self-moving wheelchair) was smoother than the wheelchair users with assistants.

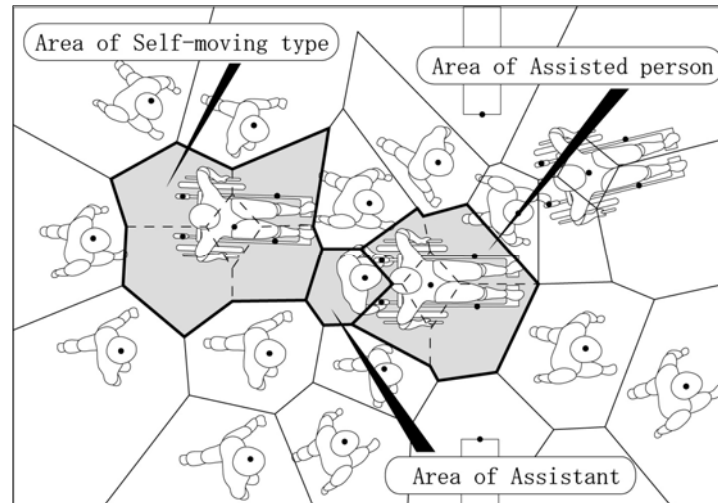


Figure 2.6 *Diagram of the wheelchair experiment* (Shimada et al. 2006)

Kobes et al. (2010) conducted real life experiments at a hotel to study human evacuation behaviour, in particular on way-finding in the case of fire. The gaming system called Behavioural Assessment and Research Tool (BART) in the Advanced Disaster Management Simulator (ADMS) was applied to develop a replica of the real hotel to understand human movement. The unannounced evacuation drills were conducted with three different situations or scenarios and the data was compared between the real world experiment at the hotel and the virtual reality experiment that used a similar hotel layout.

The scenarios developed for the research include the basic, smoke and exit sign. The experiments in the real world and virtual environment showed that humans used the main exit during the basic scenario, while during the smoke and exit sign scenario humans escaped using the nearest exit door. Three basic activities were involved during the evacuation process, namely cue validation, decision making and movement to a safe place. Fire safety behaviour was observed during the evacuation using recorded video and a questionnaire was used to confirm the behaviour.

2.4 Crowd Modelling and Simulation

The crowd modelling and simulation research involves developing a model to represent the crowd or individuals in a crowd. Based on the developed model, the crowd or individuals in the crowd are simulated in a virtual environment with a graphical interface. In general, crowd modelling and simulation is based on mathematical equations or sets of rules representing different situations or conditions of the crowd or individuals in the crowd. However, most of the models are a simplification since the movement of the crowd or individuals is considered to be very diverse and complex.

Crowd modelling and simulation was mainly selected by researchers in preference to other methods due to several advantages. Gwynne et al. (1999) commented that simulation can be used to evaluate crowds and the environment before real construction is undertaken. The best and worst scenarios of crowd movement in a building (for example) can be predicted without using real humans by carrying out the simulation many times. New theories or hypotheses on human movement in crowds also can be investigated using simulation software (Pan et al. 2006). Garson (2009) commented that simulation methods are often the most time and cost effective to use. In addition, simulation can help in identifying causes and effects and in specifying the critical parameters.

There are several reviews of crowd modelling and simulation research. For example, Zheng et al. (2009) reviewed seven types of crowd models for evacuation from buildings. The reviewed models were classified into selected features (the approaches, individual/groups, scale, space and time, situations and typical phenomena applied to the model) in order to differentiate the models. The authors commented that there is a need to combine crowd modelling methods in order to improve crowd evacuation, for example by combining the cellular automata and lattice gas models,

cellular automata with social force model, etc. In addition, there is a need to incorporate psychological and physiological factors into evacuation models.

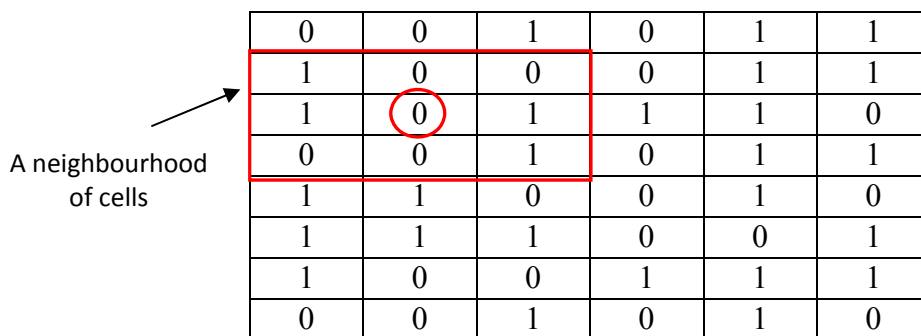
Papadimitriou et al. (2009) reviewed several crowd models related to pedestrian behaviour in urban areas. The crowd models were reviewed based on two aspects; firstly pedestrian movement and route choice and secondly pedestrian crossing behaviour. The authors commented that the crowd models related to pedestrian behaviour were more focused on the macroscopic aspects of behaviour. The interaction between the pedestrians and traffic was seldom considered in the models. The authors suggested that detailed consideration of pedestrian behaviour along the entire trip in urban areas needs to be considered in order to reflect real world behaviour.

Olenick et al. (2003) reviewed computer models related to fire and smoke as an update to previous work conducted by Friedman (1992). Although the review was not specifically related to the crowd issue, most of the selected models were applied in crowd modelling and simulation research. Based on the numerous surveys conducted, the authors reported gradual improvements in the research related to fire and smoke due to the greater database of knowledge and faster computational methods. Besides that, modelling and simulation provide predictions that are more accurate and able to predict the phenomena that were not addressed in previous models and simulations.

In this section, four models have been selected for discussion (Cellular Automata, Social Force, Lattice Gas and Agent-based models). The discussion focuses on the general definition and examples of applications developed from the model. The discussion provides an overview of how crowd modelling and simulation is conducted. Based on the models discussed, one of the models is selected for this research.

2.4.1 Cellular Automata Model

Cellular Automata (CA) (singular: Cellular Automaton) are discrete dynamical systems that model complex behaviour based on simple, local rules animating cells on a lattice. CA models have been studied in various complex systems including physics, biology and traffic modelling. Figure 2.7 shows an example of a CA model. The cells objects in the CA are located in a regular grid where each cell has its own state. The number of state possibilities is typically finite and the simplest example has the two possibilities of 1 and 0 (or can be referred as “on” and “off” or “alive” and “dead”). Each cell has a neighbourhood that can be defined in a number of ways. However, the neighbourhood is typically a list of adjacent cells as shown in Figure 2.7.



0	0	1	0	1	1
1	0	0	0	1	1
1	0	1	1	1	0
0	0	1	0	1	1
1	1	0	0	1	0
1	1	1	0	0	1
1	0	0	1	1	1
0	0	1	0	1	0

Figure 2.7 *Example of Cellular Automata model*

In CA, the initial state (time, $t = 0$) is selected by assigning a state for each cell. A new state of each cell (the current state of cell and the states of cells in its neighbourhood) is created according to some fixed rule such as a mathematical function. In general, the rule for updating the state of the cells is the same for each cell and does not change over time and is applied to the whole grid simultaneously. The updating process in CA exhibits similar behaviour to biological reproduction and evolution.

Figure 2.8 show an example of a CA model developed by Schadschneider (2002). In this model each particle (human) is given a walking direction in a 3×3 matrix of preferences that

contain of probabilities of the movement. The central element describes the probability for the particle not to move at all. The remaining 8 correspond to a move to the neighbouring cells. The matrix of preferences contains information about the preferred walking direction and speed. The walking direction and speed can be different from cell to cell depending on the geometry and aim of the pedestrians.

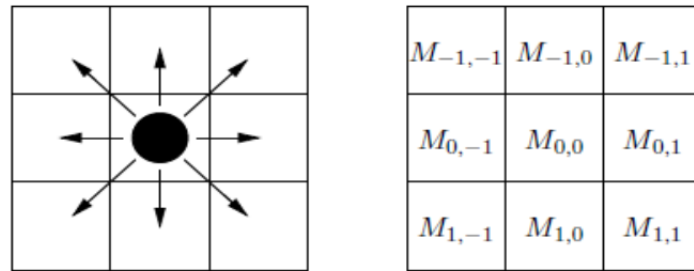


Figure 2.8 *A possible transitions and the associated matrix of preference $M = (M_{ij})$*
(Schadschneider 2002)

In the simplest case the pedestrian is allowed to move in one direction only without fluctuations and in the corresponding matrix of preferences only one element is one and all others are zero. In the following it is assumed that a matrix of preferences is given at every time step for each pedestrian. In each update step for each particle a desired move is chosen according to the probabilities. This is done in parallel for all particles. If the target cell is occupied, the particle does not move. If it is not occupied and no other particle targets the same cell, the move is executed. If more than one particle shares the same target cell, one is chosen according to the relative probabilities with which each particle chose their target. This particle moves while its rivals for the same target keep their position as shown in Figure 2.9.

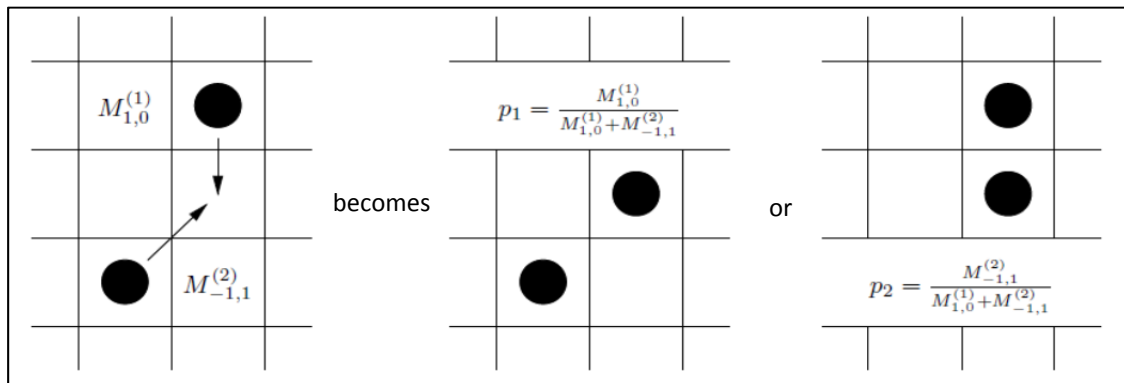


Figure 2.9 Solving conflicts according to the relative probabilities (Schadschneider 2002)

In crowd research, CA has been applied in various problem domains including the study of exit dynamics of occupant evacuation (Daoliang et al. 2006) and the exit dynamics of pedestrians in a room (Perez et al. 2002). CA also has been applied to study the effect of obstacles by simulating the evacuation process from a room with and without obstacles (Varas et al. 2007), and to simulate the bi-directional pedestrian movement and study the effect of back stepping on the critical density of phase transition (Fang et al. 2003).

According to Teknomo (2002), the CA model is simple to develop and fast in updating the data. However, the heuristic approach in updating the rules is undesirable since a CA model does not reflect the real behaviour of humans. The inherent grid of cells of a CA model can also make the behaviour of the human seem visually rough and gives the impression that the human is jumping from one cell to another.

2.4.2 Lattice Gas Model

A lattice gas model is a series of Cellular Automata models used to simulate fluid flows. As in cellular automaton, the lattice gas model comprises a lattice where the sites on the lattice (the intersection points of the lattice) can take a certain number of different states. In this model, the various states refer to the particles with certain velocities. Evolution of the simulation is conducted in discrete time steps. After each time step, the state of each site is determined by its own state and the state of neighbouring sites at the previous time step.

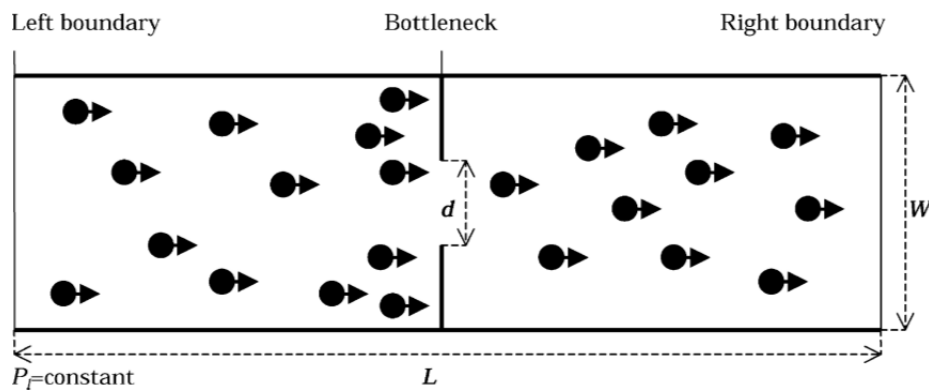


Figure 2.10 Pedestrians flow from the entrance (left boundary) towards the exit (right boundary) through bottleneck (Tajima et al. 2001)

Figure 2.10 show an example of a lattice gas model developed by Tajima et al. (2001) to simulate biased random pedestrian flow in a channel through a bottleneck. In this model, the pedestrian is represented using a circle that moves randomly from the entrance (left boundary) towards the exit (right boundary) without back step. An arrow indicates the preferential direction of the pedestrian. The length of the channel is L , the width is W and the bottleneck width is d . The density of pedestrians on the left boundary is set by a constant value P_l . A pedestrian is removed from the channel when it arrives at the right boundary and is reflected when arrive at a wall (never go out through the wall). A bias (drift) is applied to the preferential direction of random pedestrians.

In this model, there are several possible configurations of pedestrians moving towards the exit at the right boundary as shown in Figure 2.11. The crosses indicate sites occupied by other pedestrians. The transition probabilities of the pedestrian to each configuration is summarised in Table 2.1 where D represents the drift point to the exit (in this model, $D = 0.7$). At the unit time step, all pedestrians in the channel are updated once. The update procedure is the random sequential rule. In this model, the pedestrian flow in the channel is reduced to its simplest form. These include pedestrians moving with preferential directions where pedestrians cannot overlap on a single site.

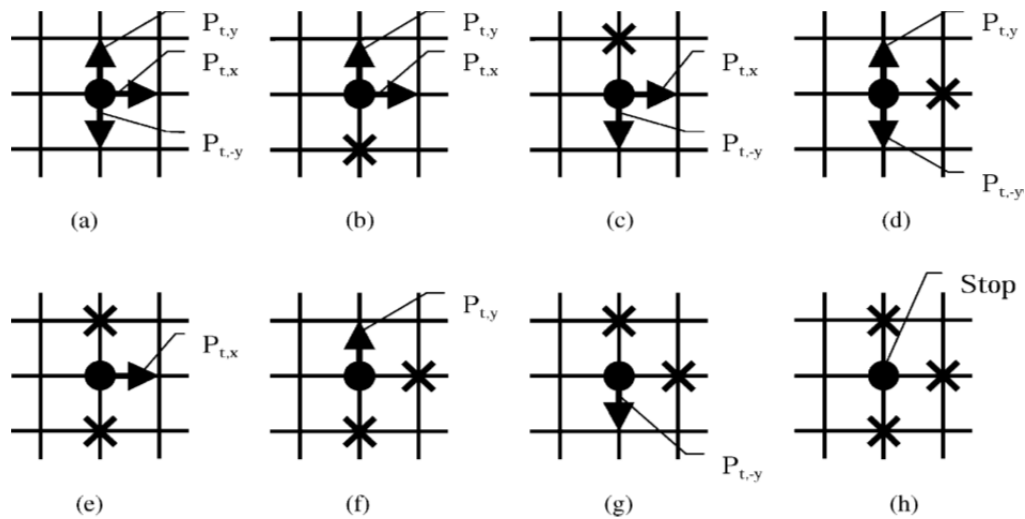


Figure 2.11 All possible configurations of a pedestrian on the square lattice (Tajima et al. 2001)

The lattice gas model has been applied in various problems such as simulating crowd flow at a hall (Tajima et al. 2001) for building design, to simulate pedestrian flow in a T-shaped channel (Tajima et al. 2002), to simulate the counter flow in the channel (Nagai et al. 2005) and to simulate the evacuation process from a classroom (Helbing et al. 2003). Lattice gas models have also been combined with other approaches to investigate the evacuation process. For example, a multi-grid model (lattice gas concept) with the force concept of a social force model to simulate interaction forces among the pedestrian was introduced by Zhang et al. (2008).

Table 2.1 *The transition probabilities of the pedestrian in each configuration*

No	Configuration	Possible Configuration
1	(a)	$P_{t,x} = D + (1 - D)/3, P_{t,y} = (1 - D)/3, P_{t,-y} = (1 - D)/3$
2	(b)	$P_{t,x} = D + (1 - D)/2, P_{t,y} = (1 - D)/2, P_{t,-y} = 0$
3	(c)	$P_{t,x} = D + (1 - D)/2, P_{t,y} = 0, P_{t,-y} = (1 - D)/2$
4	(d)	$P_{t,x} = 0, P_{t,y} = 1/2, P_{t,-y} = 1/2$
5	(e)	$P_{t,x} = 1, P_{t,y} = 0, P_{t,-y} = 0$
6	(f)	$P_{t,x} = 0, P_{t,y} = 1, P_{t,-y} = 0$
7	(g)	$P_{t,x} = 0, P_{t,y} = 0, P_{t,-y} = 1$
8	(h)	$P_{t,x} = 0, P_{t,y} = 0, P_{t,-y} = 0$ or <i>Stop Condition</i>

2.4.3 Social Force Model

The social force model was proposed by Helbing et al. (1995) as a pedestrian motion model. In this section, social force model is explained using a generalized model from Mehran et al. (2009). In this model, due to individualistic goals or environmental constraints, each human i ($i = 1, N$) with mass of m_i changes his/her velocity v_i as a result of the force F_a . The force consists of two main parts; (1) personal desire force F_p and (2) interaction force F_{int} as follows;

$$m_i \frac{dv_i}{dt} = F_a = F_p + F_{int}$$

The personal desire force F_p refers to the desired direction and velocity v_i^p that humans in crowds have when seeking certain goals and destinations in the environment. However, the crowd limits individual movement and the actual motion of human v_i would differ from the desired velocity. Therefore, the personal desire force F_p is defined with relaxation parameter τ as;

$$F_p = \frac{1}{\tau} (v_i^p - v_i)$$

The interaction force F_{int} consists of the repulsive and attraction force between humans F_{hum} based on psychological tendency to keep social distance (personal space) and an environment force F_w to avoid hitting walls, buildings and other obstacles. The interaction force is defined as;

$$F_{int} = F_{hum} + F_w$$

Detailed discussion of the interaction force F_{int} can be found in Helbing et al. (1995, 2000). The social force model also considers the effect of panic where herding behaviours appear in events like escaping from a hazardous incident. In this situation, the personal desire velocity v_i^p is replaced with;

$$v_i^q = (1 - p_i)v_i^p + p_i\langle v_i^c \rangle$$

p_i is the panic weight parameter and $\langle v_i^c \rangle$ is the average velocity of the neighbouring humans. The pedestrian i exhibits individualistic behaviour as $p_i \rightarrow 0$ and herding behaviours as $p_i \rightarrow 1$. In general, the social force model can be summarised as;

$$m_i \frac{dv_i}{dt} = F_a = \frac{1}{\tau} (v_i^q - v_i) + F_{int}$$

The social force model has also been applied in many areas of research. Seyfried et al. (2006) applied the social force model to simulate pedestrian dynamics and qualitatively analyse the influence of various approaches for the interaction between the pedestrians on the resulting velocity-density relationship. The social force model has also been applied in other crowd research such as crowd monitoring for example (Mehran et al. 2009) to observe public areas using image processing analysis.

2.4.4 Agent-Based Model

Agent-based modelling (ABM) is a computational simulation method based on computer-driven agents. According to Schieritz et al. (2003), there is no universally accepted definition of ABM especially on the kind of properties an object has if it deserves to be called an ‘agent’ including pro- and re-activeness, spatial awareness, ability to learn, social ability, intellect, etc. In crowd research, the agents are the human entities modelled in the virtual environment. The agents are an identifiable unit of computer program code which is autonomous and goal-directed.

Autonomous refers to the capability of an agent to perform independent action while goal-directed refers to s autonomous action that is directed towards the achievement of defined tasks. In general, the agents are designed with different characteristics at the individual level. When the simulation is performed, the global behaviour emerges as a result of many (tens, hundreds, thousands, etc.) individuals, each following its own behaviour rules and interacting with each other and with their environment. ABM is associated with a programming technique called object-oriented programming.

ABM has been applied to various problem domains. Based on the literature survey conducted, the major difference between the ABM systems that have been developed is the characteristics of the agent. Besides having different objectives agents have been developed based on different sources of input. For example, Augustijn-Beckers et al. (2010) applied ABM to simulate the effects of pre-evacuation behaviour and exit choice strategies. The agents were divided into three categories (or behaviours) known as Officers, Leavers and Followers. The officers were modelled as trained emergency personal or staff that had professional evacuation training. The main behaviour of the officers consists of clearing the building. The officer will run to the leavers or followers who have not yet started the evacuation process and will prompt the agents to evacuate.

The leavers represent the shoppers or staff that can evacuate on their own. The main behaviour of the leavers was the evacuation behaviour especially the pre-evacuation time and the exit choice. Lastly, the followers represent the people that not evacuate independently but will evacuate together with either a “leaver” or “officer”. In this research, the behaviour of the leavers was derived from the questionnaire and literature review data conducted before the simulation.

Pan et al. (2006) applied ABM to simulate the social behaviour of humans during emergency situations. The simulation model was categorised into three levels that consisted of different rules; the individual, the interactions among individuals and the group and the environment. The three levels developed in the research were the examination of crowd behaviour from the perspectives of human decision-making and social interaction. The levels developed were considered as the computational simulation framework for the simulation that was based on the understanding of the emergence and nature of crowd behaviour. The three levels of categorization were not independent but intimately related and often overlapped. The simulation was able to simulate social behaviours such as competitive, queuing and herding behaviours.

Schelhorn et al. (1999) applied ABM to simulate and predict pedestrian behaviour in urban centres. The agents were developed based on two broad characteristics; socio-economic and behavioural. The socio-economic characteristic refers to the income and gender of the agent. Both characteristics were used to create the activity for the agent such as the sequence of locations which the agents intend to visit in the town centre. On the other hand, the behavioural characteristic refers to detailed behaviour of the agents including the speed, visual range and agents’ focus to follow the scheduled activity. The research is important to understand the way in which town centres work and to plan pedestrian movement in accessing the town centres.

2.5 Features in Crowd Modelling and Simulation

In this section, the selected crowd modelling methods, namely Cellular Automata (CA), Lattice Gas (LG), Social Force (SF) and Agent-based (AB) are analysed and categorised based on the selected features of characteristics, scale and situation. The categorisation is useful in understanding the approaches of each model and to select a suitable model that will be applied for this research.

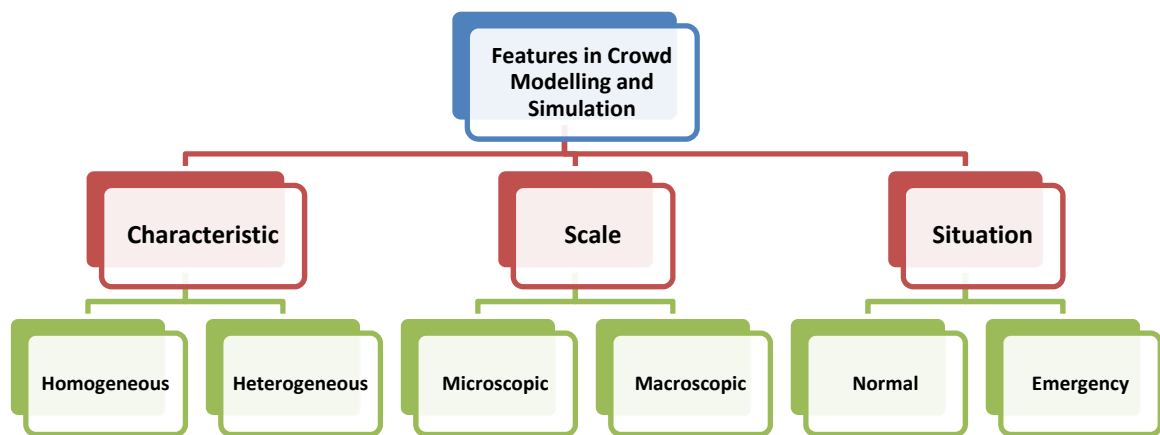


Figure 2.12 Different features describing crowd research

Figure 2.12 show the distribution of each feature. Each feature is divided into two focus areas where characteristic is divided into homogeneous and heterogeneous, scale into microscopic and macroscopic while situation is divided into normal and emergency. Table 2.2 show the distribution of selected crowd model based on the selected features.

Table 2.2 *Distribution of selected crowd models based on selected features*

Model	Selected Features					
	Characteristic		Scale		Situation	
	Homogeneous	Heterogeneous	Microscopic	Macroscopic	Normal	Emergency
<i>CA</i>	√		√		√	√
<i>LG</i>	√		√		√	√
<i>SF</i>	√		√		√	√
<i>AB</i>		√	√		√	√

2.5.1 Characteristic

Characteristic refers to the type of subject that is focused on within the crowd. The types of subject can be individuals or a group. In general, there are two types of characteristics which are homogeneous individuals/groups and heterogeneous individuals/groups. Homogeneous characteristic refer to individuals or groups that have the same parameters. For example, all individuals in a crowd might have the same gender, behaviours, age, walking speed etc. On the other hand, the heterogeneous characteristic consist of individuals or groups with variety in parameters such as male and female (gender); young and old people (age); slow, medium and fast walking speed etc.

Homogeneous characteristic can be found in crowd modelling and simulation that is based on mathematical equations including cellular automata, lattice gas and social force models. Heterogeneous characteristic can be found in crowd modelling and simulation that is based on agents (agent-based modelling). The advantages of heterogeneous characteristic are the ability to design different individuals at one time of simulation. For example, (Kaup et al. 2008) applied age differences to model and simulate the movement of the crowd in the virtual environment. The movement of the entities in the virtual environment reflected the movement of real human (adult and older people) in the real world.

2.5.2 Scale

Scale refers to the size of the crowd that is observed. There are two different scales that can be applied in crowd research, the microscopic and the macroscopic. At the microscopic scale every human in a crowd is treated as an individual or particle where detailed analysis of human movement and behaviour is considered and measured, for example individual speed and interaction (Teknomo 2002). On the other hand, at a macroscopic scale the humans in a crowd are aggregated into a flow, average speed and area module like the movement of a fluid. There is no consideration of detailed human movement and behaviour since the main concern of macroscopic crowd study is space allocation for humans in the crowded area.

The microscopic scale has been widely applied in crowd research. All four selected models have been applied at the microscopic scale. The microscopic scale shows that the collective phenomena that emerge from the complex interactions between many individuals become important in crowd modelling and simulation. For example Yang et al. (2005) applied the microscopic scale to model and simulate crowd movement with kin behaviour using a combination of cellular automata and social force models. Tajima et al. (2001) and Yamashita et al. (2003) simulated crowd flow using the lattice-gas model while Helbing et al. (2003) simulated evacuation dynamics using the social force model. A macroscopic scale has been widely applied in the fluid dynamics model (not selected for discussion). For example, Hughes (2003) applied a fluid dynamics model to represent crowd movement.

2.5.3 Situation

Situation refers to the conditions applied for the crowd research. There are two major situations that are usually considered during model development, normal and emergency. In a

normal situation, every human in the crowd has a different goal and can be observed from the speed, flow and behaviours of the crowd. However, in an emergency situation the entire crowd has the same goal which is to escape from the emergency situation such as a fire hazard. Wang et al. (2008) simulated an example emergency situation in common with most crowd research that focuses on emergency situations such as in crowd modelling and simulation. All selected models can be applied to simulate both situations.

2.6 Summary

This chapter gave an overview of crowd research limited to the three areas of crowd monitoring, experimental studies with crowds and crowd modelling and simulation. Each research area was discussed based on the general definition and examples of its application. Crowd monitoring has the advantages of tracking human movement and behaviour using automatic systems. However, the method is restricted by illumination, computer processing power and size of the crowd. Experimental studies with crowds are a useful method to understand human movement and behaviour. Unfortunately, the movements and behaviours are not ‘natural’ and can be affected by other external factors. The human movement and behaviour is also limited to the laboratory setting or spaces.

Crowd modelling and simulation is considered the appropriate method related to this research. The method offers a solution to consider ‘real’ human movement and behaviour in the real world as an input data. Among the four models selected for discussion in this chapter, the Agent-based modelling (ABM) approach is considered the most applicable to model and simulate similar movement and behaviour of human from the real world to the virtual environment. ABM has the ability to model the crowd using heterogeneous characters which gives advantages in developing ‘inclusive’ characters considering adults, older people and those with disabilities. Besides that, ABM is applicable to observe the crowd in a microscopic scale where detailed

analysis of human movement and behaviour can be considered and measured. Lastly, ABM can be used to simulate the normal and emergency situations of the crowd.

In conclusion, the main focus area for the crowd research work reported here is shown in blue in Figure 2.13. The main approach is on crowd modelling and simulation using agent-based modelling. In the next chapter, the crowd modelling and simulation research is revisited to investigate the human behaviour involved. The review is conducted in order to understand what types of behaviours have been selected and how the behaviours have been applied by other researchers. The next chapter also reviews the essential aspects needed before simulating the behaviour in the virtual environment and lastly the discussion is focused on the use of gaming software for simulation.

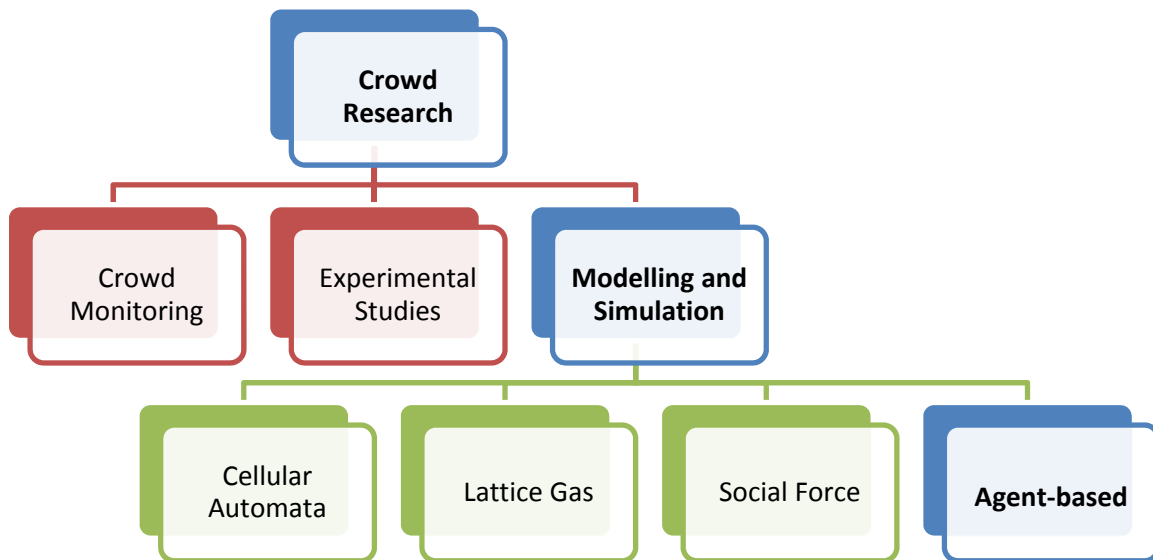


Figure 2.13 Selected focus area for this research (in blue)

Chapter 3: Review of Human Behaviour in Crowds and the Application of Gaming Software

This chapter reviews the human behaviour that has been applied in crowd modelling and simulation research including the avoidance, competitive, queuing, herding and kin behaviours. The review also focuses on the existing methods of incorporating human behaviour into the virtual environment and provides an overview of the software selected for simulation.

3.1 Human Behaviour in Crowd Modelling and Simulation

Human behaviour is widely studied and applied in crowd research especially in crowd modelling and simulation. Human behaviour for crowd modelling and simulation is considered as challenging subject matter since each human has different characteristics and there are many factors affecting human behaviour. There are also difficulties in developing human behaviours that are believable (Rymill et al. 2005) and reflect on the real world behaviour of humans.

In general, human behaviour can be categorised into the sociological, psychological and physiological aspects. According to Gwynne et al. (1999) the sociological, psychological and physiological aspects of humans can be observed from human interaction. Social behaviour is considered to be human to human interaction or how the humans interact with each other. Psychological behaviour is considered to be human to structure (information about the building etc.) interaction and is reflected in the information processing and decision-making from experience or objectives that humans have during movement. The human to environment interaction is

considered as the physiological behaviour where the behaviour is affected by human ability and capability.

Several works have been conducted in crowd modelling and simulation to consider the elements of sociological, psychological and physiological aspects of humans. For example, Cherif et al. (2010) applied the socio-psychological state for virtual agents in crowd simulation in order to develop natural human behaviour. The virtual agents were capable of interacting with the environment and other agents. Kobes et al. (2010) applied virtual reality using gaming software as a method to evaluate human behaviour in crowds and compared the results with crowd experiments at a hotel.

Kaminka et al. (2006) applied the social comparison theory to model crowd behaviour. The model attempts to close the gap between the theories of social psychology and the computational model. Hou et al. (2009) conducted psychometric tests to investigate the psychological aspects of human movement in crowds. The psychometric test results were applied as the input for the simulation. Pelechano et al. (2005) integrated a psychological model into a crowd simulation system in order to obtain believable emergent behaviours. The examples show that human behaviour is an important aspect to be considered in crowd modelling and simulation. Zheng et al. (2009) also commented that human behaviour should be considered in crowd modelling and simulation in order to reflect on the genuine situation in the real world.

In this section, five types of human behaviour that were considered and applied in the crowd modelling and simulation research are selected as examples for discussion. The focus is on the general definition and importance of the behaviours. The selected behaviours were avoidance, competitive, queuing, herding and kin.

3.1.1 Avoidance Behaviour

Avoidance is a behaviour that occurs when a human avoids another human (or obstacles) during the movement. Rymill et al. (2005) indicated that avoidance behaviour can occur in two scenarios; avoiding oncoming people and avoiding people travelling in the same direction. Based on the psychological input, Rymill et al. (2005) stated that when a human avoids oncoming people, a much greater distance is taken to perform the behaviour in a low density crowd while in a high density crowd individuals pass at shorter distances. In low density crowds humans change their movement path and detour around the oncoming people. On the other hand, in a high density crowd there was not a total detour and avoidance of contact but a slight angling of the body, a turning shoulder and almost imperceptible side step known as a ‘step-and-slide’.

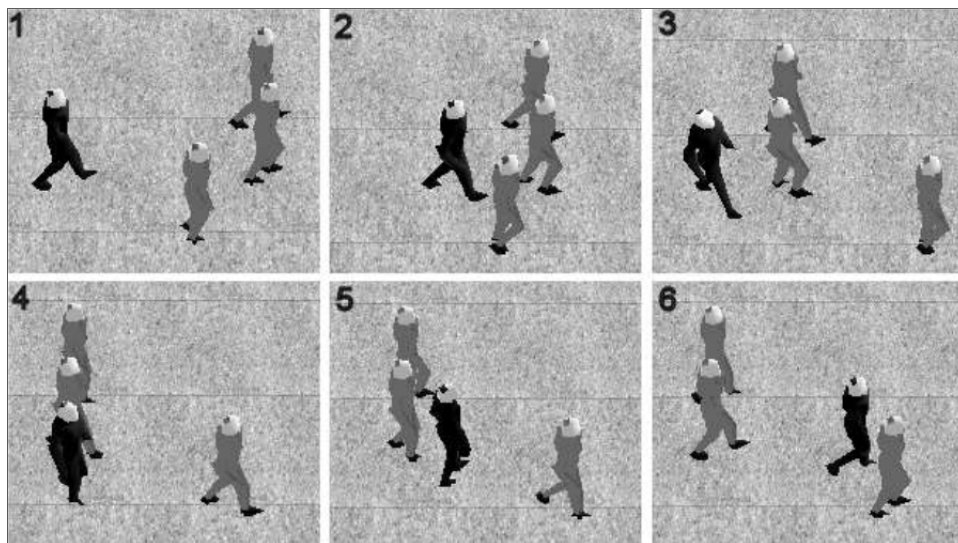


Figure 3.1 Avoiding behaviour by overtaking (Rymill et al. 2005)

Rymill et al. (2005) also stated that when a human avoids another human moving in the same direction, there are two options available; overtake or slow down and walk behind the people in front. During movement in the same direction humans do not position themselves directly behind the pedestrian at the front, but behind their shoulder in order to monitor conditions ahead. If a human decides to overtake the people in front, as shown in Figure 3.1, they can weave their way

through their own lane of people or step off the pavement onto the road. If a pedestrian in a cluster wishes to travel faster, then they can either thread their way through the cluster or go around it.

Avoidance behaviour is a behaviour that is widely applied in crowd modelling and simulation research. For example, Pelechano et al. (2007) developed the HiDAC (High Density Autonomous Crowds) system to simulate high density crowds that are moving in a natural manner within a dynamically changing virtual environment. The HiDAC system provides efficient perception for the virtual agent to avoid static and dynamic obstacles through a cell and portal graph. The cell corresponds to a room and contains information about all the static objects and the lists of dynamic objects within the room are rapidly updated as the agent traverses the environment. The agent can obtain the obstacle data by querying the cell.



Figure 3.2 *Avoiding behaviour simulation* (Cherif et al. 2010)

Ondřej et al. (2010) developed a vision-based approach of collision avoidance for interactive crowd simulation. The vision-based collision avoidance model was developed based on the argument that humans rely on the optical flow (vision) of the perceived environment to achieve collision-free navigation. Cherif et al. (2010) applied the avoidance behaviour based on forces of attraction and repulsion in the agent. The avoidance behaviours that consist of avoidance of collision and avoidance of obstacles were affected by the type of situation (normal and panic), the

personal space (broad, average and narrow) and the level of patience that were influenced by a set of psychological and sociological rules in the model. Figure 3.2 shows the avoidance behaviour simulation (Cherif et al. 2010).

3.1.2 Competitive Behaviour

Competitive behaviour occurs when humans compete with each other during movement especially at exit doors or bottleneck areas. In competitive behaviour each human has less consideration about others where for example every individual wants to leave through the exit door earlier due to different objectives, timing, conditions, etc. In many cases competitive behaviour leads to an inefficient exit process or evacuation since there are minor collisions or there is collision avoidance behaviour among the humans in the crowd.

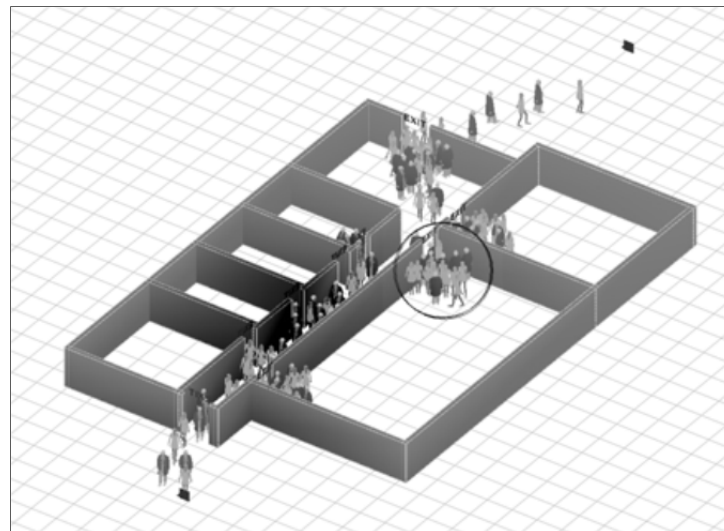


Figure 3.3 Competitive behaviour at the exit doors (Pan et al. 2006)

Competitive behaviour is considered as dangerous behaviour for older people and people with disabilities since they have a limited ability and capability to compete with the young and able-bodied. However, there is a possibility that older people and people with disabilities perform

the competitive behaviour more than the young and able-bodied. Competitive behaviour was applied by Pan et al. (2006) for human behaviour simulation as shown in Figure 3.3. In the simulation, the competitive behaviour occurs when the virtual agents move towards the goal (exit door) at maximum speed and do not negotiate and avoid collision with other agents.

3.1.3 Queuing Behaviour

Queuing is behaviour where humans leave through an exit door in an orderly manner. Queuing behaviour is opposite to competitive behaviour and humans respect the line and wait for others to walk first (Pelechano et al. 2007). The formation of a queue is largely the manifestation of self-organization and does not lead to clogging at exits but often leads to more effective evacuation (Pan et al. 2006). Figure 3.4 shows an example of queuing behaviour simulation. In the simulation, all agents exhibit waiting and formed a line when there was no available space in front of them.

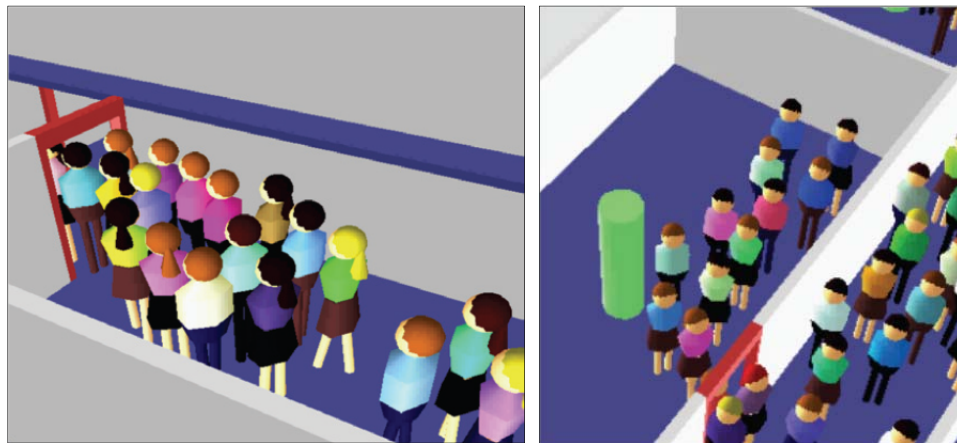


Figure 3.4 Example of queuing behaviour (Pelechano et al. 2007)

3.1.4 Herding Behaviour

Herding behaviour is observed for example during an exit process when there are two exits, one of which is clogged while the other is not fully utilized. Herding behaviour can be illustrated as in Figure 3.5. Herding behaviour is the behaviour that differentiates the behaviour of humans and fluids (Low 2000). In herding behaviour, humans have the ability to decide the movement. However, herding behaviour is based on the popular choice or is affected by other people. Sometimes herding behaviour can help people exit safely and at other times it may cause blockages at an exit even though another exit is available. In simulation, the herding behaviour can occur as the agents move towards the goal (exit door) and choose the exit door that has the biggest crowd or is ‘most popular’.

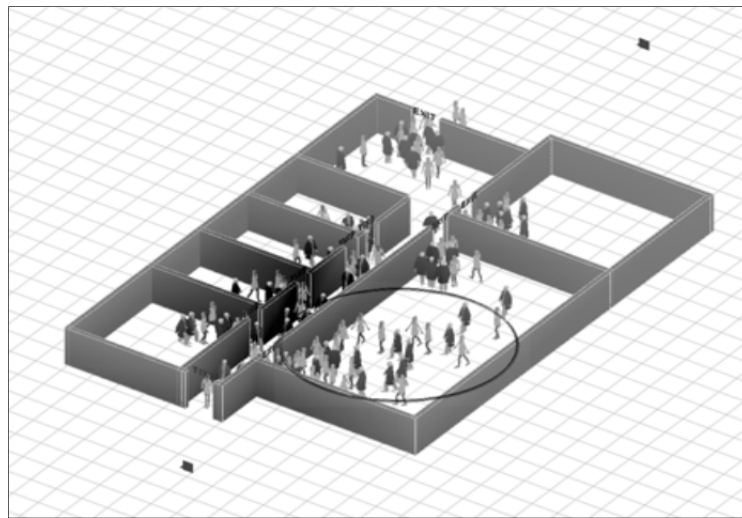


Figure 3.5 Herding behaviour at the exit doors (Pan et al. 2006)

3.1.5 Kin Behaviour

Kin is a social behaviour where people move together in a group because of certain relationships. A family that consists of father, mother and children moving together at the shopping complex or group of students moving together at a train station are examples of kin behaviour. Kin behaviour affects the crowd during an emergency situation. Since there are bonding relationships between the group (kin behaviour), the members of the group tend to wait for one and another during the evacuation process.

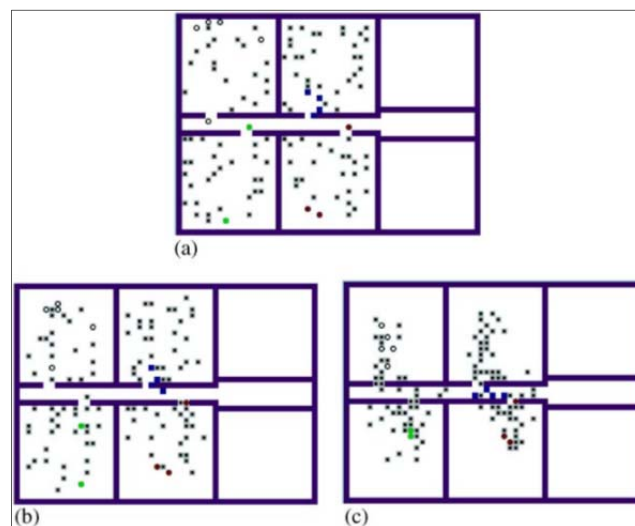


Figure 3.6 *Kin behaviour simulation using two exits case* (Yang et al. 2005)

According to Yang et al. (2005) kin behaviour in an emergency produces phenomena in the crowd such as incoherence, jamming, gathering, backtracking and waiting. Figure 3.6 shows an example of kin behaviour that was developed based on a Cellular Automata model. Based on the simulation, the authors concluded that the psychology of going with the crowd was not always harmful and proper kin behaviour was beneficial in improving the evacuation efficiency.

3.2 The Behavioural Perspective in Simulation

The understanding of human behaviour in the real world is important input for human behaviour simulation in the virtual environment. Various methods have been applied to incorporate the behavioural aspect within simulations. Gwynne et al. (1999) suggested that there were five different behavioural systems developed for human behaviour simulation in virtual environments and these are known as; *no behavioural rule*, *functional analogy behaviour*, *implicit behaviour*, *rule based behavioural system*, and *artificial intelligence based behavioural system*. The systems were summarised based on a review of the evacuation models. In this section, the behavioural system is discussed as an input to understand the method applied for human behaviour simulation in a virtual environment.

3.2.1 No Behavioural Rule

No behavioural rule refers to a system which is based only on the physical movement of the agent and the physical representation of the building geometry. The *no behavioural rule* was applied in early generations of software such as EVACNET+ (Kisko et al. 1985). The system was developed based on the nodes that represented the building and spaces (such as offices and workplaces) with the connection between the building spaces represented by arcs (Kisko et al. 1986).

3.2.2 Functional Analogy Behaviour

The *functional analogy behaviour* model is based on an equation or set of equations to represent humans or a crowd. In this behavioural system, all humans have similar behaviour

(homogeneous individuals/group) where the movement and behaviour is dependent on the equation applied. The behavioural system simplifies the individual behaviour and some of the functions are not taken from real world behaviour of humans. The example of *functional analogy behaviour* includes the Cellular Automata, Lattice Gas and Social Force models that were discussed in Chapter 2. Figure 3.7 shows the simulation of room evacuation with an obstacle using the Social Force model with a mobile grid system.

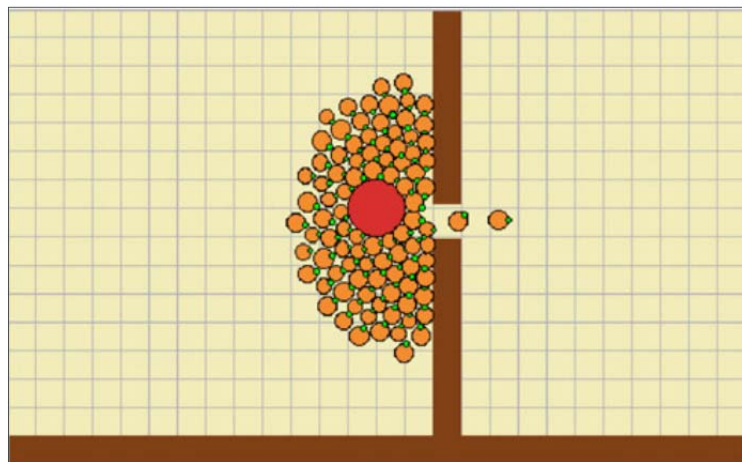


Figure 3.7 *Simulation of room evacuation with an obstacle using Social Force model*
(Saboia et al. 2012)

3.2.3 Implicit Behaviour

Implicit behaviour is a simulation model that is developed based on secondary data. The secondary data can be the sociological, psychological or physiological data from other researchers. However, the validity and accuracy of the system depends on the secondary data. Simulex (Spearpoint 2004) and Wayout (Shestopal 2005) are examples of models that are based on *implicit behaviour*. Figure 3.8 shows an example of emergency simulation for fire protection developed based on the Simulex model.

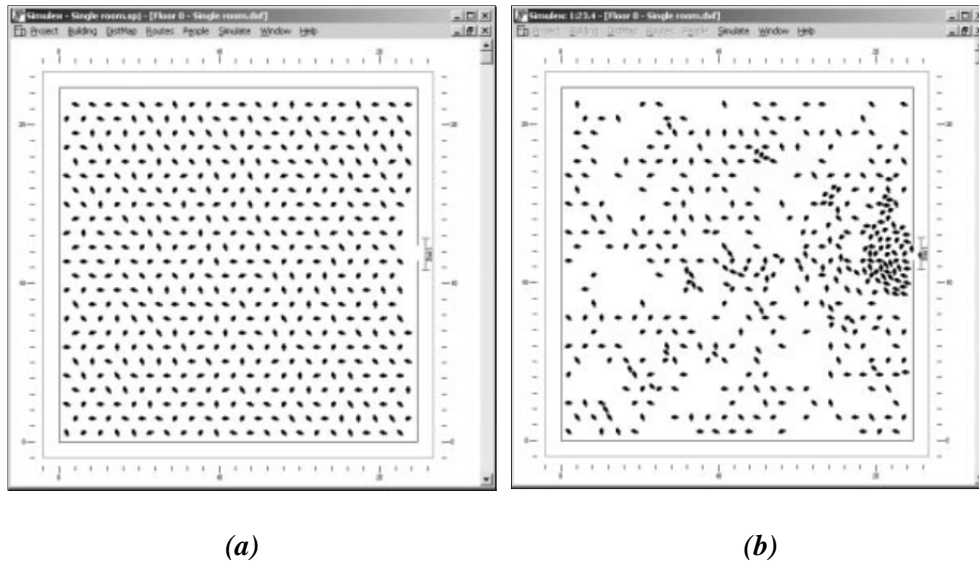


Figure 3.8 Room evacuation simulation using Simulex model; (a) initial setup, (b) during evacuation (Spearpoint 2004)

3.2.4 Rule Based Behavioural System

A *rule based behavioural system* is based on a set of rules that are defined in the algorithm and implemented in the virtual agent for decision making. For example, the rule might be, “*If the room is filled with smoke, I need to leave using the nearest exit*” or “*Check the timetable before taking the train*”. The problem with *rule based behavioural systems* is that some rules are based on a simplistic method. Besides that, the system does not have an ability to ‘learn’ the situation through repetition and denies the possibility of natural variations in outcome. Figure 3.9 shows an example of a rule based behavioural system for train station simulation (human crowd management) developed by Schweiss et al. (1999).



Figure 3.9 *Simulation of human movement at a train station using a rule based behavioural system* (Schweiss et al. 1999)

3.2.5 Artificial Intelligence Based Behavioural System

An *Artificial intelligence based behavioural system* is an example of approach that applies artificial intelligence for the movement of virtual agents. The artificial intelligence has the ability to simulate human behaviour similarly to a real world crowd in aspects such as the movement, intelligence and effects of the surroundings. Advancement of computer languages and computing power has resulted in frequent use of artificial intelligence methods. Figure 3.10 shows an example of artificial intelligence based behavioural system using the Principle of Least Effort (PLE). The algorithm known as PLEdestrians (Guy et al. 2010) was applied to compute a biomechanically energy efficient trajectory for each individual in a multi-agent simulation.



Figure 3.10 Simulation of Trade Show Floor consist of 1,000 agents using an artificial intelligence based behavioural system (Guy et al. 2010)

3.3 General Requirement for Simulation Software

The simulation method is widely applied for crowd research and different types of software have been applied for the simulation. This section focus on an overview of the general requirements for simulation software. The discussion is a guideline for software selection for this research. The input of the discussion was based on work conducted by Haron et al. (2012), Ronchi et al. (2011) and Castle (2007).

3.3.1 Visualization

Visualization or the graphical ability of simulation software plays a major role in the selection of the method. In recent years, crowd simulation is focusing more on the three-dimensional (3D) visualization rather than two-dimensional (2D). 3D visualization is able to present more realism and provide more understanding of human movement and behaviour in virtual environments. It is also beneficial if the simulation software has the ability to import 3D

files or images from other software such as CAD (Computer Aided Design). This is to ensure that a greater variety of 3D files or images can be used within the simulation.

3.3.2 Development Cost

Cost is another main consideration before selecting the simulation software. Software that is too expensive or needs extra licenses to operate or upgrade is not applicable for the research. Low development cost simulation software always become the priority. Research by Haron et al. (2012) for example put low development cost as their main priority for software evaluation and selection.

3.3.3 Usability of the Software

Usability refers to the ease of use and learnability of the software. User friendly software always uses a simple coding or commonly used computer language. This to ensure the software is more efficient to use. User friendly software also gives more satisfaction to the user as it will take less time to accomplish the development.

3.3.4 Artificial Intelligence (AI)

Artificial Intelligence (AI) is the area of computer science that focuses on creating machines or coding using intelligent behaviours. In crowd modelling and simulation research, in addition to visualisation, AI is most important in developing more realistic movement and behaviour in the virtual environment. Most crowd modelling and simulation research relies on the ability of AI in the software for successful implementation.

3.3.5 Support System

Good software always comes with a good package of supporting systems. This includes the basic documentation explaining how the software works, examples or a website that is able to communicate with the user. The supporting system is important so that continual development using the software can be made and new features can be incorporated within the source code. In recent years, the development of group forums is always beneficial where the users, programmers and authors are available to help on any problem related to software development.

3.4 Overview of DarkBASIC Professional Software

Based on the general requirement of simulation software discussed in Section 3.3, the DarkBASIC Professional (DBPro) software was selected for this research. DBPro is gaming software that was developed based on the BASIC computing language. The language has been enhanced specifically to aid the creation of games programs (Stewart 2009) and contains none of the complexity of other commonly used computer languages for commercial games such as Microsoft Visual C++ (Syed Shazali 2010). The language has many unique commands for displaying graphics, controlling images and creating 2D and 3D images. Programs can be developed for low development costs (Watcharasukarn et al. 2011) while all games created using the language are license and royalty free.

DBPro has a greater support for media software such as the ability to import a 3D model directly from other programs such as 3D Studio Max and the ability to create and import new functions into the compiler using C or C++ coding. DBPro also has a website (<http://www.thegamecreators.com/>), newsletter and forum to help in solving certain problems related to coding where the authors, other professional and amateur programmers are available. The

website, newsletter and forum are also regularly updated with patches and new knowledge related to DBPro. DBPro includes the DarkAI expansion pack where extra commands are available to help create objects that are based on artificial intelligence or are computer controlled. DarkAI adds ‘intelligent’ behaviour into the software with commands including path finding, teams, entity command, manual control, avoidance, etc. Figure 3.11 shows a screen shot for command writing in DBPro.

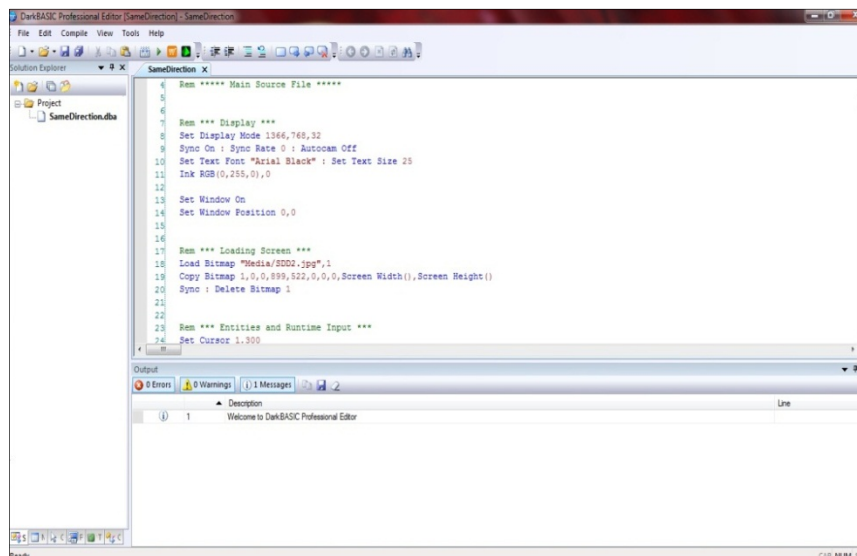


Figure 3.11 *DarkBASIC Professional screen shot*

3.5 Examples of DarkBASIC Professional Software Application

DarkBASIC Professional (DBPro) software is widely used for the games application. However, as it is able to simulate a graphical scene in 2D and 3D design, the software is also used in other applications. For example, Park et al. (2008) applied DBPro for criminology research. The research was developed under Crime Prevention Through Environmental Design (CPTED), a multidisciplinary research that determined criminal behaviour using environmental design. The objective was to reduce the occurrence and fear of crime whilst improving quality of life.

In Park et al. (2008), the pedestrian agent model was developed using two types of personalities known as ‘bold’ and ‘fearful’. The agent was simulated to navigate within the virtual urban environment and make a choice of route according to their fear of crime. The fear of crime considered in the research include narrow passageways without escape routes, hidden corners, dumpsters and threatening individuals on the street. The simulation results show that the ‘bold’ personality moves in the shortest path towards the movement objective compared to the ‘fearful’ personality due to a path selection affected by ‘fear factors’. The simulation was validated in a virtual environment as shown in Figure 3.12 using a real human.



Figure 3.12 *Example of virtual environment* (Park et al. 2008)

DBPro was also applied by Watcharasukarn et al. (2011) as a survey tool to collect travel behaviour data and monitor travel behaviour adaptation. The developed tool was based on the virtual reality role-playing game known as Travel Activity Constraint Adaptation Simulation (TACA SIM). The tool was used to investigate the adaptability of human travel behaviour under the simulated scenario of rapid fuel price increases. As shown in Figure 3.13, the TACA SIM was divided into three types of question (shown in Figure 3.13 as (a), (b) and (c)) that collected different data from humans for transport engineering analysis.

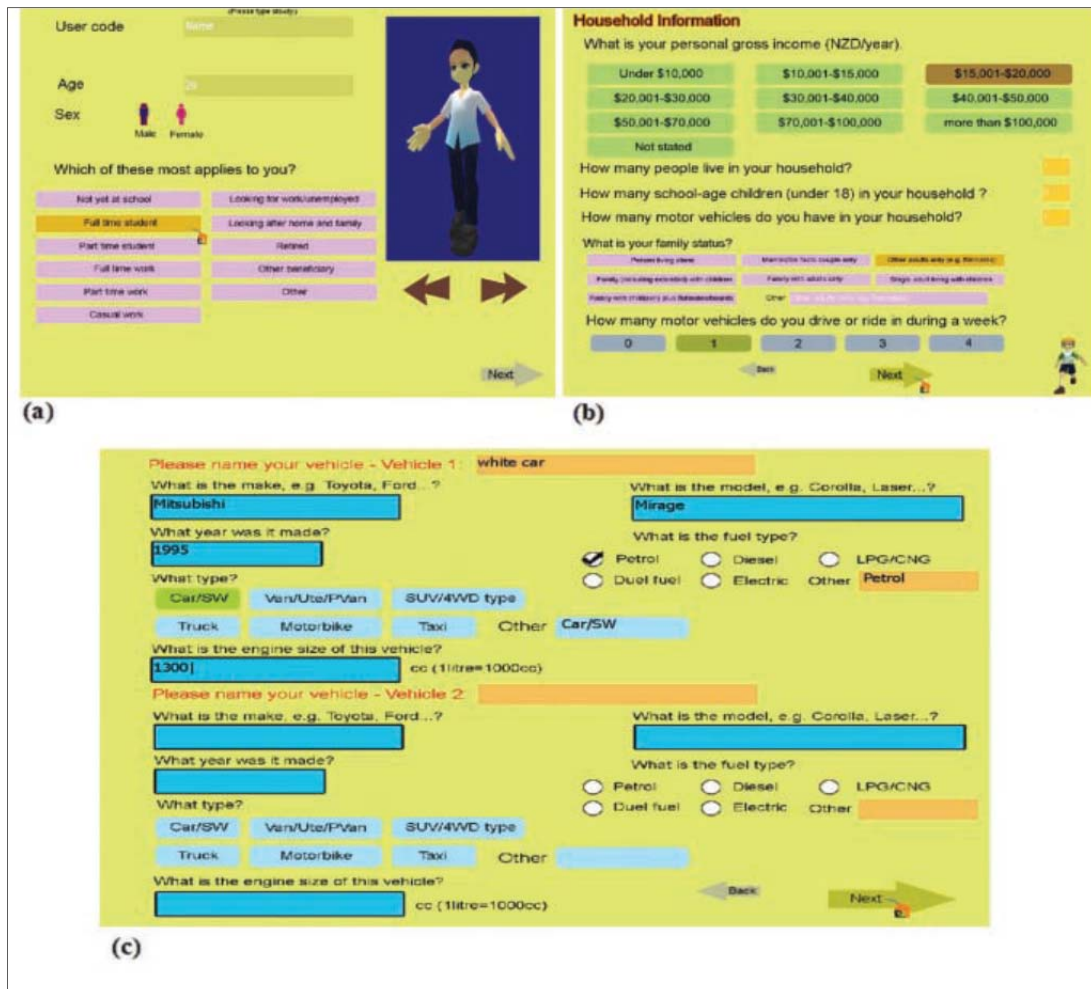
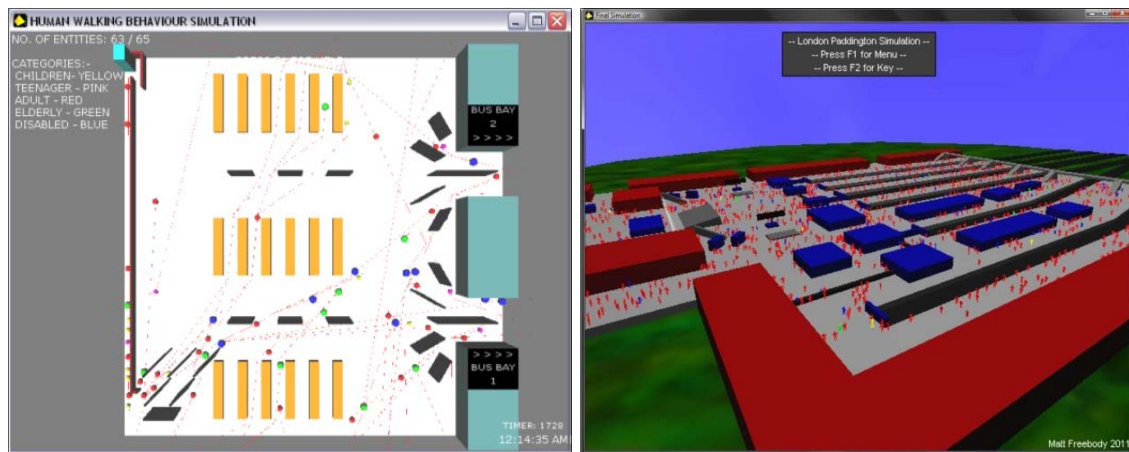


Figure 3.13 *The TACA SIM graphical user interface* (Watcharasukarn et al. 2011)

The first level in Figure 3.13 (a) generates the personal information of the user, the second level Figure 3.13 (b) collects the activity and location data while the third level in Figure 3.13 (c) collects the response data to various predetermined high fuel price scenarios. In TACA SIM, the user filled in the survey using game mode where the users need to answer the question and play with the avatar. The user also needs to choose the journey using a Google map interface. At the end of the survey, the user is given the scenario where the fuel price is increased and the user needs to choose the transportation mode. The advantages of TACA SIM is the ability to collect the conventional travel demand data more quickly in a more enjoyable environment and at low development cost.

The examples from Park et al. (2008) and Watcharasukarn et al. (2011) show that DBPro is interactive software that can be used to simulate and evaluate human behaviour. However, the most related research that applied DBPro software for human movement and behaviour simulation was conducted by Syed Shazali (2010) and Freebody (2011). In Syed Shazali (2010) the Human Intelligent Movement Software (HIMS) was developed to simulate human movement in a virtual environment and was applied to predict the movement at different places and layout designs such as the bus station as shown in Figure 3.14 (a). Freebody (2011) applied the DBPro software to visualise the movement of the crowd during the peak and off-peak times at London Paddington underground station as shown in Figure 3.14 (b).



(a)

(b)

Figure 3.14 Example of human behaviour simulation at; (a) a bus station (Syed Shazali 2010) and (b) a train station (Freebody 2011)

Both studies attempted to understand the involvement of older people and people with disabilities at the crowded area within the simulation. However, the input data for agent (virtual human) characteristics for both studies were considered insufficient. Syed Shazali (2010) conducted video observation at shopping malls to understand human behaviour in the real world. Due to privacy, ethical and security issues, the video was recorded from a side view of movement and not from an aerial view. Therefore, there is a probability that some important factors that affect the human movement and behaviour in crowded area have been overlooked. It is also possible that

human movement and behaviour at a shopping mall might be slightly different from that found in a transportation area. This can influence the selection of suitable parameters for the agent in the virtual environment. Lastly, the agent in the virtual environment was only represented in 2D using different coloured circles to show the movement.

Freebody (2011) managed to simulate human movement in large crowds with four different characteristics defining the agents; adult, young person, elderly and disabled or adults with infants. However, the movement of agents in the virtual environment were limited to commands to avoid obstacles and collisions whilst following the shortest path to destinations. The movement paths of the agents towards the destinations (within the virtual environment) were also decided earlier within the source code. The movement paths are considered to be too specific or fixed and no analysis of movement can be made using the simulation.

The simulation is considered appropriate to demonstrate human movement in crowds using a virtual environment, but is nevertheless not appropriate to analysing movement. The drawbacks from the previous work are important input for this research. Therefore, many factors should be considered before conducting this research including the method used to acquire the input data from human movement and behaviour from the real world and the strategy adopted in developing a simulation model for the virtual environment that reflects movement in the real world.

3.6 Summary

This chapter has provided an overview of human behaviour that has been applied in crowd modelling and simulation research. Due to the uniqueness of humans, not all behaviour in the real world can be applied in the virtual environment simulation. The behaviours that are to be simulated in the virtual environment were accordingly defined based on the ability of the selected software. Avoidance, competitive, queuing, herding and kin behaviour were among the behaviours that have been simulated by researchers.

Based on the review conducted, the avoidance, competitive and queuing behaviours are observed to be easily affected by the movement direction of the human. For example, avoidance behaviour occurs when humans move in the same and opposite directions while competitive and queuing behaviour only occurs when humans move in the same direction movement. On the other hand, herding and kin behaviours are considered to be complex for observation and simulation. The movement direction alone cannot represent the behaviour.

An artificial intelligence based behavioural system was selected for this research. The DarkBASIC Professional (DBPro) gaming software was selected for the virtual environment simulation due to its ability to simulate 2D and 3D designs. The software is also considered to be user friendly and has low development costs. DBPro has been applied previously for crowd modelling and simulation. However, there is still a gap within the research conducted and it can be improved within this research.

The next chapter will discuss the video observational studies applied for this research. The observational method is selected in order to observe and understand the real world crowd including the movements and behaviours involved. The movement and behaviour derived from the observational studies will be applied later for the simulation.

Chapter 4: Video Observational Studies

This chapter presents the development of a video observational method to understand human movement and behaviour in crowded areas. The major discussion is on the application of conceptual behaviour, observational supporting software and an observational database in analysing human movement and behaviour from recorded video. It also reports an overview of the selected subjects, location and recording session for the studies.

4.1 Introduction

The video observational method is widely applied in ergonomics and image processing research. In ergonomics research, video observational methods were preferred over self-reporting because it offers better validity and reliability (Pehkonen et al. 2009). The video observational method was widely applied to observe whole body movement such as assessing the load in low back, shoulders and lower extremities. According to Dempsey et al. (2005) and Pascual et al. (2008) although there is still no universal method to observe all kinds of jobs, a wide variation of observational methods have been applied in ergonomics research.

For example, Pehkonen et al. (2009) applied the video observational method in real time from videotape to assess musculoskeletal load in kitchen work. The assessment focused on the movement of hands and wrists based on postures, time (duration and frequency) and force requirements. The video observational method was also applied as an input for an interactive computer controlled video based analysis system (Yen et al. 2002). The recorded video was applied to compare the analysis time and inter-analyst reliability using posture classification and spectral

analysis. Noldus et al. (2000) applied a video observational method as input in developing tools for computer-aided behavioural observation software. The software was able to collect, manage, analyse and present the observational data based on predefined behaviours using an assigned key code.

One of the prominent characteristics of systematic observation is the use of a predefined list of behavioural codes that have been developed for particular observational studies. The coding schemes were the instruments of measurement for observational research where the behaviours were specified based on the research objective (Noldus et al. 2000). Besides developing predefined lists of behavioural codes that reflected specific needs, there are many examples of behavioural codes developed to assist the observational studies such as Rapid Upper Limb Assessment (RULA) (McAtamney et al. 1993), Rapid Entire Body Assessment (REBA) (Hignett et al. 2000), Ovako Working Posture Analysis System (OWAS), Quick Exposure Check (QEC) (David et al. 2008) and others.

The video observational method provides an opportunity to observe some unpredictable or natural movement and behaviour of humans, although the issues of privacy and security require serious consideration. In this research, the video observational method is applied as an input in analysing human movement and behaviour in crowded areas from the real world. Figure 4.1 shows an overview of the steps taken to understand and analyse human movement and behaviour from the recorded video. The video observational method starts with recording the crowd at the selected location and time. The recorded video was viewed once to get an overview of the crowd location to reflect on the research objective.

Subsequently, conceptual behaviours were developed to assist the observation process. The conceptual behaviours are a set of behaviour rules or codes that have been developed based on the major human movements of free, opposite and same direction. The conceptual behaviour set becomes the reference document to be referred to in order to avoid any confusion or exclusion of

any humans during the analysis process. The analysis process is the last step taken in the process where the observational supporting software and observational database is applied for that purpose. A detailed discussion of each step taken is presented in Sections 4.2 to 4.4 of this chapter.

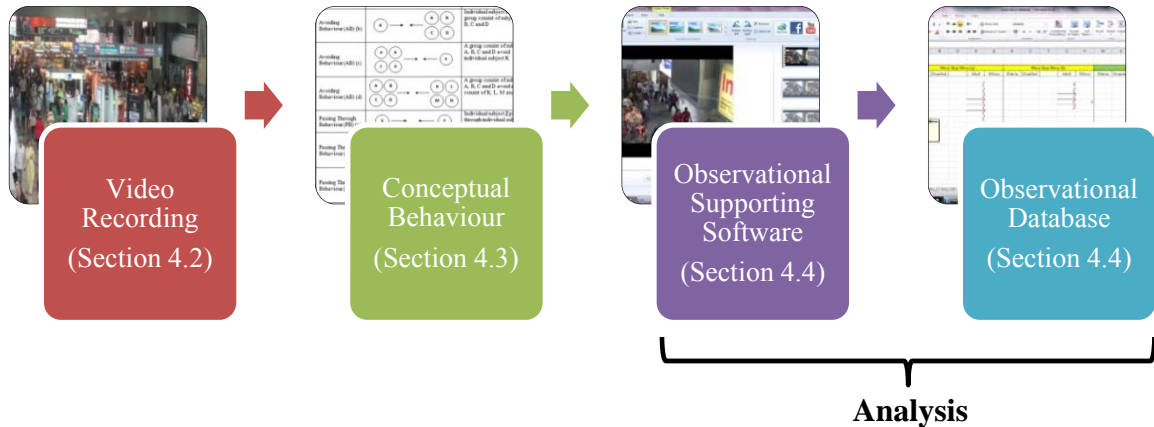


Figure 4.1 *The observational process flow*

4.2 Video Recording

Video recording is a process to record human movement and behaviour in crowded areas. There were two important considerations before conducting the video recording including selecting the appropriate location and planning the video recording session. During the video recording, images of humans in the crowd were captured from an aerial view so as to capture the whole human body from the top or head area. This make it easier to observe human movement and behaviour through the recorded video. The usage of the top or head area as a reference point was widely applied in image processing research such as in Hoogendoorn et al. (2003, 2005) and in crowd experiment research by Kretz et al. (2006b) and Seyfried et al. (2009).

4.2.1 Overview of Selected Location

Several places were selected as video recording locations included a mosque, lecture room and transportation area. All recordings were conducted in Malaysia since it was easier to gain permission to record crowd movement and behaviour from an aerial view. In this research, the transportation area called the Stesen Sentral Kuala Lumpur as shown in Figure 4.2 was selected as the video recording location.



Figure 4.2 Overview of the Stesen Sentral Kuala Lumpur, Malaysia (KL-SENTRAL 2009)

Stesen Sentral Kuala Lumpur is the largest transportation hub or transfer station in Malaysia integrating all major transportation networks including trains, buses and taxis services from Kuala Lumpur to other areas in Malaysia. Stesen Sentral Kuala Lumpur provides the Express Rail Link (ERL) services to Kuala Lumpur International Airport (KLIA) and to the new administration centre of Malaysia known as Putrajaya. Stesen Sentral Kuala Lumpur is also the largest interchange for the Light Rail Transport (LRT) system and KTM (Malaysia Railway) commuter as well as the

KTM Intercity trains running Singapore-Kuala Lumpur-Bangkok. The buses and taxis are also easily accessed within the area. Detailed information related to Stesen Sentral Kuala Lumpur is available from KL-SENTRAL (2009).

The selection of Stesen Sentral Kuala Lumpur as the observation area is closely related to the objectives of the AUNT-SUE project that promoted research towards sustainable environments (Marshall et al. 2005). The transfer station also has special characteristics to be considered for crowd modelling and simulation such as differences in activities, time pressure and movement patterns (Daamen et al. 2002). The activities refer to different types of activities that might arise at the transfer station such as waiting for other people, buying tickets, shopping and others. Time pressure refers to conditions where there is a possibility to observe people either hurrying to catch the public transport (such as train or bus) and in more relaxed situations. It is in the nature of transfer station that movement patterns of the crowd are based on arrivals/departures determined by the public transportation timetable. However, the selected location is a large area, and a specific area needs to be selected for video recording purposes.

In this research, the focus area was on the exit door (and it's near surroundings) located at the crowded interchange connecting the public transportation systems including trains, buses and taxis within the transportation hub. The selected area is located on the ground floor of the building and is highlighted in yellow in Figure 4.3, the building map of the Stesen Sentral Kuala Lumpur. In order to record humans in the crowd from an aerial view, a video camera (Canon Legria, Model HF10) was located on the first floor at the opposite side of the observation area (represented by the yellow arrow in Figure 4.3). An overview of the selected location is shown in Figure 4.4 where there is a ticket machine, a stall and a shop located at the exit door area (highlighted in yellow). The exit door was selected for the research since the area can supply considerable human movement and behaviour in crowded areas.

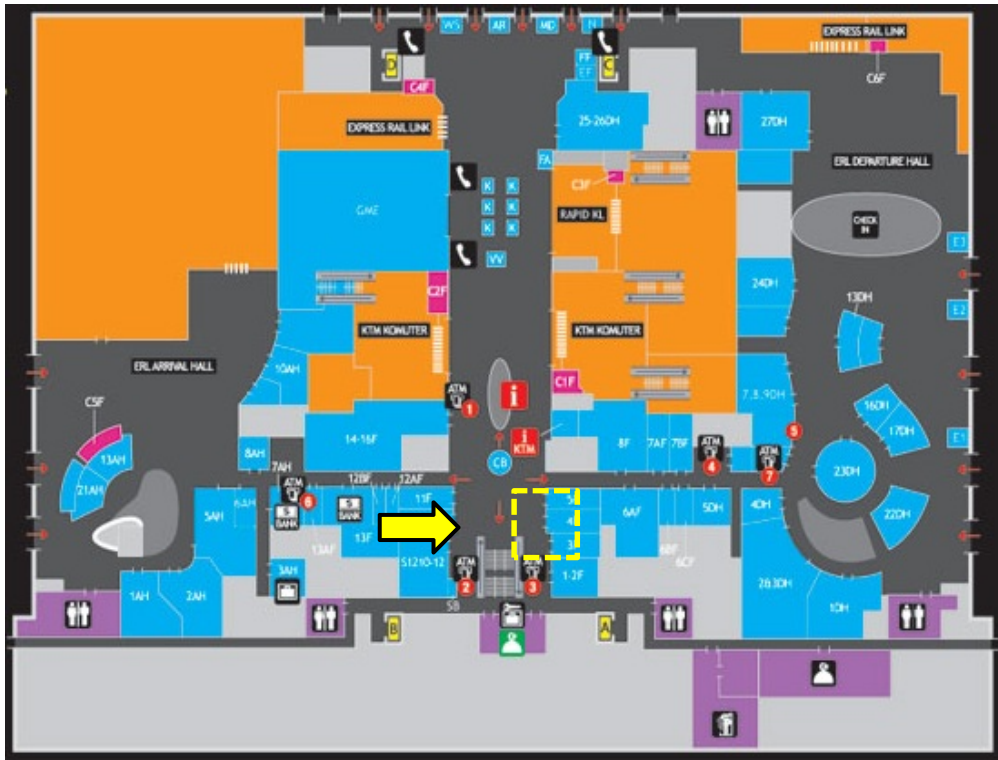


Figure 4.3 The observation area map (KL-SENTRAL 2009)

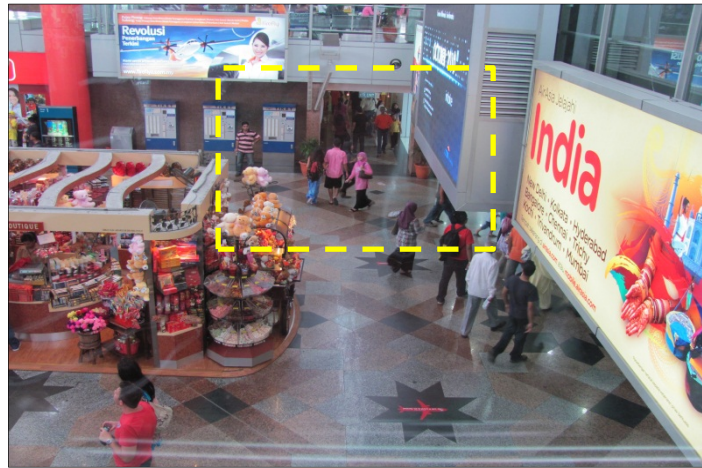


Figure 4.4 Overview of the selected observation area

4.2.2 Overview of Video Recording Session

The video recording session is shown in Table 4.1. In total six hours of recording were conducted divided into morning, afternoon and evening sessions. Each session was conducted for one hour where morning session started at 7:30 am, the afternoon session at 12:00 pm and the evening session at 5.00 pm. The three sessions were repeated for weekend and weekdays. The weekend session was on Sunday, 17 April 2011 and the weekday session was on Thursday, 21 April 2011.

Table 4.1 *Observation date and time*

Time	Duration	Weekend (Sunday)	Weekday (Thursday)
7:30 am – 8:30 am	1 hour	17/4/2011	21/4/2011
12:00 pm – 1:00 pm	1 hour	17/4/2011	21/4/2011
5:00 pm – 6:00 pm	1 hour	17/4/2011	21/4/2011

The weekday session was determined as the peak time where people start using the transportation service. For example, the morning and afternoon session deals with people using the transportation service to travel to and from the workplace. The afternoon session covers the people moving for afternoon lunch. The weekend session was determined to deal with a leisure time crowd with also some people using the transportation service to travel. Besides the consideration of peak and off-peak times, these sessions were at times when there was a wide diversity of people using the transportation area including older people and people with disabilities.

4.2.3 Overview of Selected Subjects

The overall objective of this research was to consider the diversity of people, age and capability. In this research the subjects were summarized into four categories as follows;

1. Older people of 65 years of age and above. In general, older people have a decline in their capabilities due to increased age. Older people can be observed through their reduced strength, imperfect vision and slow movement speed.
2. People with disabilities are individuals that have physical or mental impairments which have a substantial and long-term adverse effect on the ability to perform normal day-to-day activities (DIRECTGOV 2011). Some of people with disabilities used special devices such as wheelchair or white cane to move.
3. Able-bodied adults refer to normal adults that are able to move around independently without any help from other people or any need to rely on other devices to move.
4. Others refer to the children or workers moving around with trollies, cleaning devices or other equipment.

4.3 Conceptual Behaviour

Conceptual behaviours are a set of behaviours rules or codes that was developed to assist the observational analysis from the recorded video. The conceptual behaviours were developed based on observing the physical movement of individual humans in crowded areas (without any contact or direct communication) and the understanding of human movement and behaviour from the literature survey in Chapter 3. Figure 4.5 shows the development process of conceptual behaviours. The process starts with defining the focus subject for the research which is the individual human in a crowd. Each individual human in a crowd will be observed and the focus is on the movements that are performed known as free, same and opposite direction movement.

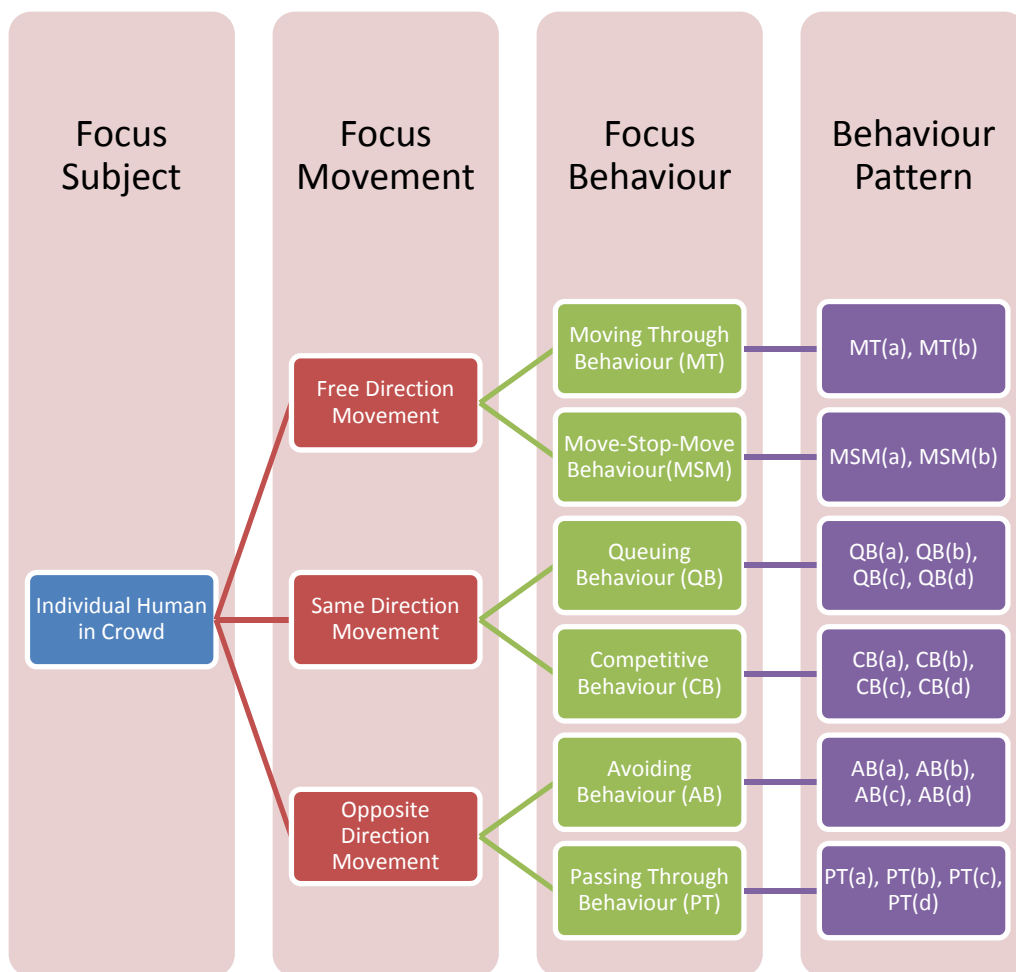


Figure 4.5 Conceptual behaviours diagram

From each focus movement, there are two types of behaviour that can be derived. Therefore, in total there are six different types of behaviours derived from three types of movement. The focus behaviours are known as Moving Through, Move-Stop-Move, Queuing, Competitive, Avoiding and Passing Through. The six behaviours were either derived based on the input from literature survey or newly defined for this research. After carefully going through each behaviour, there was a possibility to derive different types of behaviour patterns from each behaviour based on different movement scenarios.

As shown in Figure 4.5 there are two behaviour patterns that can be derived from Moving Through and Move-Stop-Move behaviour in Free Direction movement. Four behaviour patterns can be derived from Queuing and Competitive behaviour in Same Direction movement and in Opposite Direction movement four behaviour patterns can be derived from Avoiding and Passing Through behaviour. The possibility of having different types of behaviour patterns from focus behaviours was developed based on the assumption that different movement scenarios can occur when individual humans move in the crowded areas. However, the behaviour pattern might or might not be performed in the real world.

As a result, in conceptual behaviours, human movement was considered as a scenario to acquire the human behaviour or behaviour pattern. The idea of having behaviour patterns from movement scenarios was based on scenario building that has been developed in product design. Scenario building is a tool for exploration, prototyping and communication at an early stage of the product design process. The scenario is defined as a set of users, a context and a set of tasks that users perform or want to perform (Fulton Suri et al. 2000). Thus, the conceptual behaviour is a foundation for what is going to be observed and analysed so that better insight into human behaviour can be achieved whilst avoiding any confusion during the observation process due to the large volume of movement and behaviour within the recorded video. A detailed discussion on the focus movements, focus behaviours and behaviour patterns is conducted in Sections 4.3.1 to 4.3.3.

4.3.1 Free Direction Movement

Free direction movement refers to human movement from one point of interest to another point of interest. In this research, the point of interest is referred to as human movement within the observation area as previously shown in Figure 4.4. As shown in Figure 4.6 there are two types of behaviour that can occur during free movement and these are known as Moving Through and Move-Stop-Move behaviour.

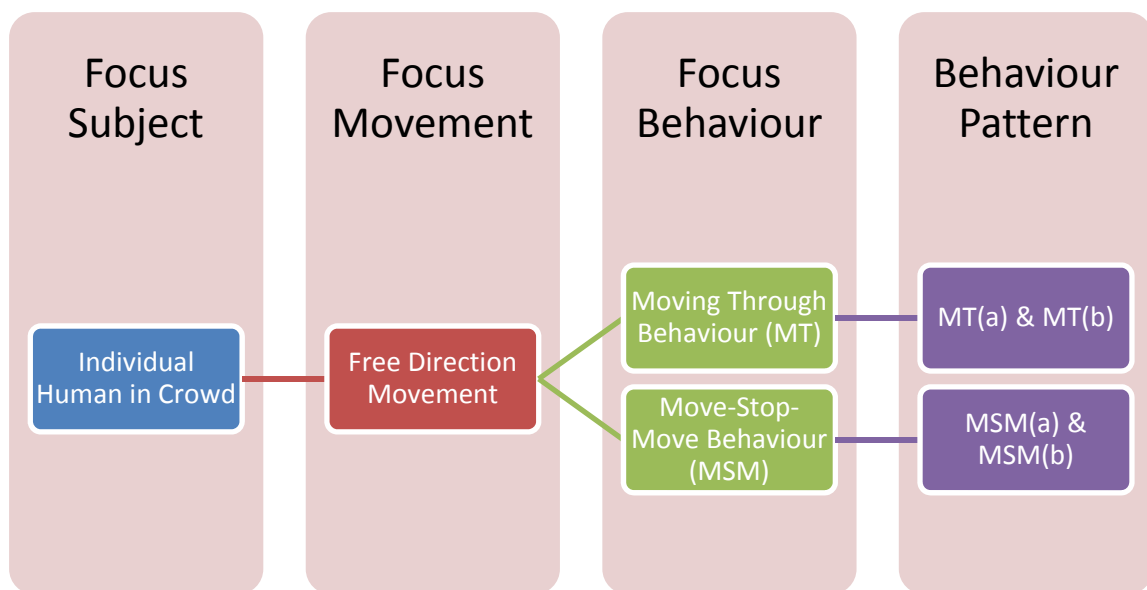
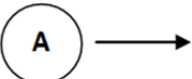
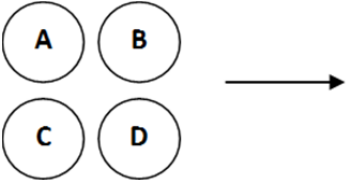


Figure 4.6 Behaviour pattern in Free Direction movement

The behaviours are newly defined for this research work and have not previously been applied in other research. The behaviours reflect the different types of human movement from different types of direction in the observation area. It also related to the size of the observation area that is considered to be limited or small. In other words, the free direction movement attempts to generalize different types of movement (besides opposite and same direction) that can be observed in the observational area from the recorded video, where some of the movements (individual movements) appeared for a short time. In free direction movement humans are considered to have enough space to move and not to be facing any obstacle or constraint during the movement.

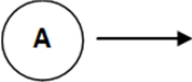
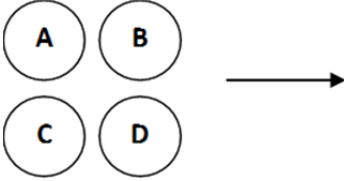
Moving Through is defined as the behaviour where humans just move through the observation area without any specific concern. There is no activity performed by the subject besides walking or running. Two different types of behaviour pattern are derived from the behaviour defined as Pattern (a) of Moving Through behaviour **(MT)(a)** and Pattern (b) of the Moving Through behaviour **(MT)(b)**. **(MT)(a)** focuses more on the *individual human* movement whereas **(MT)(b)** focuses more on the *individual human in a group*. The idea of having individuals and individuals in a group is to observe the differences that might appear when a human moves alone or together with other humans. Table 4.2 shows the detailed explanation regarding the two possibilities of behaviour pattern in Moving Through behaviour.

Table 4.2 Human movement scenario and Moving Through behaviour pattern

<i>No</i>	<i>Human Movement (Scenario)</i>	<i>Description (Rules)</i>	<i>Behaviour (Pattern)</i>
1.		Individual subject A moving through the pathway	Moving Through behaviour (MT)(a)
2.		A group consist of individual subject A, B, C and D moving through the pathway	Moving Through behaviour (MT)(b)

Move-Stop-Move is defined as the behaviour where humans have to stop a few seconds or a few minutes during the movement to perform some other related task such as buying a ticket, using a mobile phone, waiting for someone or looking for information. Two different types of behaviour pattern are derived from the behaviour defined as Pattern (a) of Move-Stop-Move behaviour **(MSM)(a)** and Pattern (b) of the Move-Stop-Move behaviour **(MSM)(b)**. **(MSM)(a)** focuses more on the *individual human* movement whereas **(MSM)(b)** focuses more on the *individual human in a group*. Table 4.3 give a detailed explanation regarding the two possibilities of behaviour pattern in Move-Stop-Move Behaviour.

Table 4.3 Human movement scenario and Move-Stop-Move behaviour pattern

<i>No</i>	<i>Human Movement (Scenario)</i>	<i>Description (Rules)</i>	<i>Behaviour (Pattern)</i>
1.		Individual subject A move, stop and move in the pathway	Move-Stop-Move behaviour (MSM)(a)
2.		A group consist of individual subject A, B, C and D move, stop and move in the pathway	Move-Stop-Move behaviour (MSM)(b)

4.3.2 Same Direction Movement

Same direction movement consists of Queuing and Competitive behaviours. The Queuing and Competitive behaviours can easily be observed when humans enter or exit a door. Queuing behaviour is the manifestation of self-organization where individual humans create a line to enter or exit the door. On the other hand, in Competitive behaviour humans have less consideration for each other and each individual tries to enter or exit the door as quickly as possible. As shown in Figure 4.7 there are four different types of behaviour pattern that might be derived from each behaviour (Queuing and Competitive).

In other research, the Queuing and Competitive behaviours were focused more at the bottleneck exit door such in Pelechano et al. (2007) and Pan et al. (2006) where only one individual can enter the area at one particular time. However, in this research the attempt is made to observe Queuing and Competitive behaviours in more open spaces such as in the observation area shown previously in Figure 4.4. Although the focus area of the observation in this research is at the exit door, the area is considered wide enough to accommodate several people at one time. This research is aimed at understanding what factors can affect the behaviours if the observation is conducted in

more open space and how the behaviours can occur. This can contribute to a greater understanding of human movement and behaviour in crowded areas.

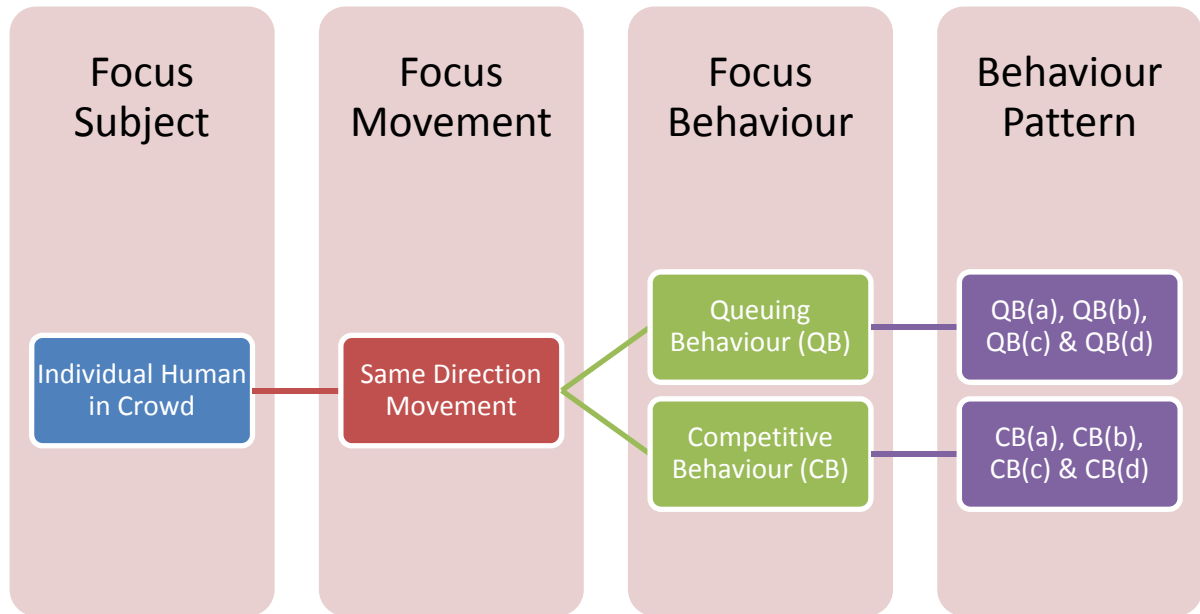

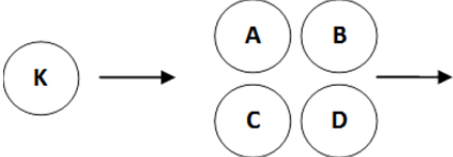
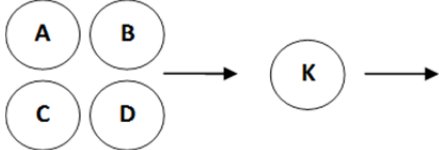
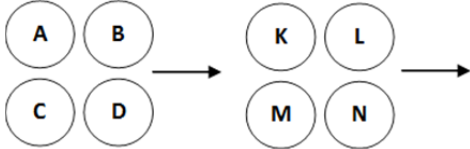


Figure 4.7 Conceptual behaviour of Same Direction movement


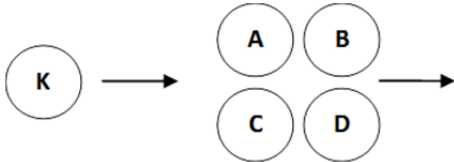
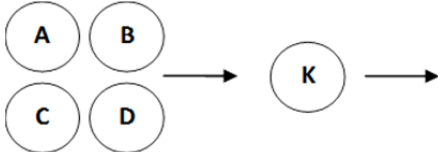
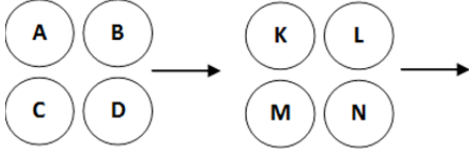
The movement scenario and behaviour pattern of Queuing behaviour is shown in Table 4.4. In this scenario another individual can be in a static or dynamic condition. The behaviour pattern is known as Pattern (a) of Queuing behaviour **(QB)(a)**, Pattern (b) of Queuing behaviour **(QB)(b)**, Pattern (c) of Queuing behaviour **(QB)(c)** and Pattern (d) of Queuing Behaviour **(QB)(d)**. **(QB)(a)** refers to a scenario where an *individual human queues at the back of another individual during the movement*. **(QB)(b)** refers to a scenario where an *individual queues at the back of a group of individuals during the movement*. **(QB)(c)** refers to a scenario where a *group of individuals queues at the back of individuals during the movement* and **(QB)(d)** refers to a scenario where a *group of individuals queues at the back of another group of individuals during the movement*.

Table 4.4 Human movement scenario and Queuing behaviour pattern

No	<i>Human Movement (Scenario)</i>	<i>Description (Rules)</i>	<i>Behaviour (Pattern)</i>
1.		Individual subject G queuing behind subject H	Queuing behaviour (QB)(a)
2.		Individual subject K queuing behind a group consist of subject A, B, C and D	Queuing behaviour (QB)(b)
3.		A group consist of subject A, B, C and D queuing behind individual subject K	Queuing behaviour (QB)(c)
4.		A group consist of subject A, B, C and D queuing behind a group consist of K, L, M and N	Queuing behaviour (QB)(d)

The movement scenario and behaviour pattern of Competitive behaviour is shown in Table 4.5. In this scenario another individual can be in a static or dynamic condition. The behaviour pattern is known as Pattern (a) of Competitive behaviour **(CB)(a)**, Pattern (b) of Competitive behaviour **(CB)(b)**, Pattern (c) of Competitive behaviour **(CB)(c)** and Pattern (d) of Competitive behaviour **(CB)(d)**. **(CB)(a)** refers to a scenario where an *individual human competes with another individual during the movement*. **(CB)(b)** refers to a scenario where an *individual competes with a group of individuals during the movement*. **(CB)(c)** refers to a scenario where a *group of individuals competes with an individual during the movement* and **(CB)(d)** refers to a scenario where a *group of individuals competes with another group of individuals during the movement*.

Table 4.5 Human movement scenario and Competitive behaviour pattern

<i>No</i>	<i>Human Movement (Scenario)</i>	<i>Description (Rules)</i>	<i>Behaviour (Pattern)</i>
1.		Individual subject G compete with subject H	Competitive behaviour (CB)(a)
2.		Individual subject K compete with a group consist of subject A, B, C and D	Competitive behaviour (CB)(b)
3.		A group consist of subject A, B, C and D compete with individual subject K	Competitive behaviour (CB)(c)
4.		A group consist of subject A, B, C and D compete with a group consist of individual subject K, L, M and N	Competitive behaviour (CB)(d)

4.3.3 Opposite Direction Movement

Opposite direction movement refers to the condition where a human meets another human travelling in the opposite direction, for example when moving along a pathway. Upon meeting each other during the movement there are two possible behaviours that can occur and these are defined as Avoiding and Passing Through behaviours as shown in Figure 4.8.

Avoiding refers to the behaviour where the human gives way to other people or performs an avoidance route (in Figure 4.8 the Avoiding behaviour is illustrated as the individual A). On the other hand, Passing Through refers to the behaviour where humans do not consider others or their surroundings during the movement. The major concern is to reach the targeted area within the planned route (in Figure 4.8 the Passing Through behaviour is illustrated by the individual B). As

shown in Figure 4.9 there are four different types of behaviour pattern that might be derived from each Avoiding and Passing Through behaviours.

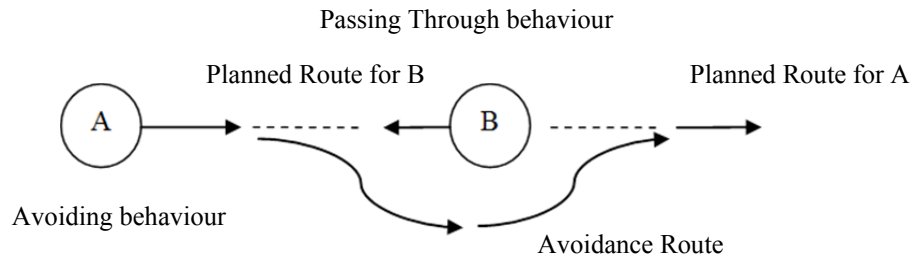


Figure 4.8 *Avoiding and Passing Through behaviour*

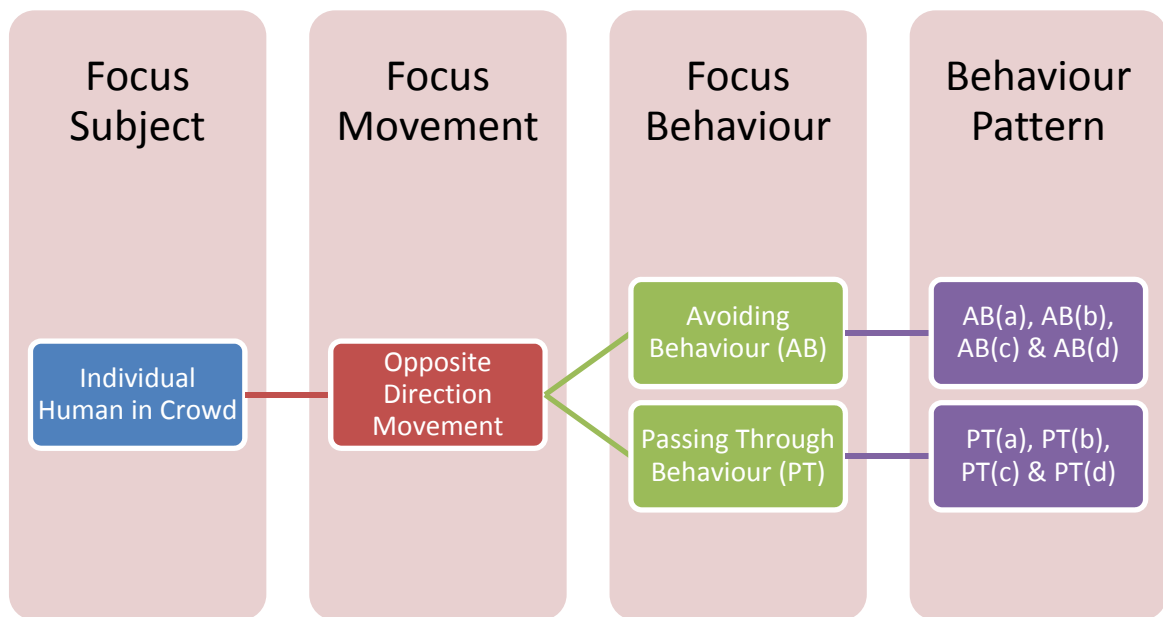
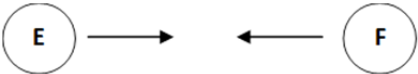
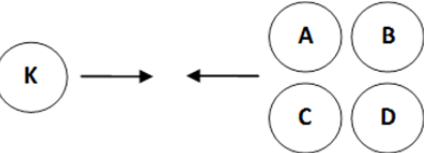
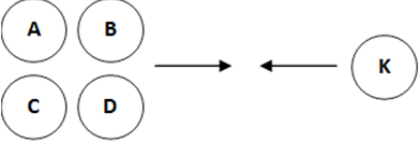
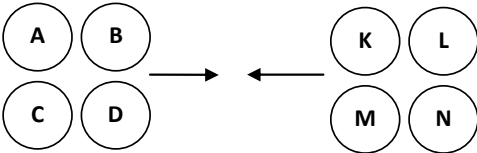


Figure 4.9 *Conceptual behaviour of Opposite Direction movement*

Most research only focuses on Avoiding behaviour within crowd research such as in Rymill et al. (2005) and Cherif et al. (2010) and ignore or do not consider the Passing Through behaviour. The Passing Through behaviour was only found in Syed Shazali (2010), in the different context of a shopping complex. In this research, both Avoiding and Passing Through behaviours are considered (with slightly different definitions) within the opposite direction movement. The idea is

to show that during the movement humans have the choice to consider or not consider others. This is a natural behaviour that can be realized when humans encounter others moving on the opposite direction and the behaviour can be observed using the observational method. It is also interesting to observe whether or not older people and those with disabilities consider others during their movement.

Table 4.6 Human movement scenario and Avoiding behaviour pattern

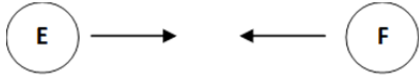
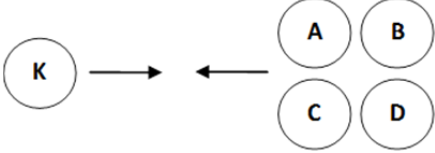
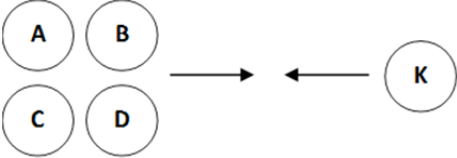

No	<i>Human Movement (Scenario)</i>	<i>Description (Rules)</i>	<i>Behaviour (Pattern)</i>
1.		Individual subject E avoid individual subject F	Avoiding behaviour (AB)(a)
2.		Individual subject K avoid a group consist of subject A, B, C and D	Avoiding behaviour (AB)(b)
3.		A group consist of subject A, B, C and D avoid individual subject K	Avoiding behaviour (AB)(c)
4.		A group consist of subject A, B, C and D avoid a group consist of K, L, M and K	Avoiding behaviour (AB)(d)

The movement scenario and behaviour pattern of Avoiding behaviour is shown in Table 4.6. In this scenario another individual can be in a static or dynamic condition. The behaviour pattern is known as Pattern (a) of Avoiding behaviour **(AB)(a)**, Pattern (b) of Avoiding behaviour **(AB)(b)**, Pattern (c) of Avoiding behaviour **(AB)(c)** and Pattern (d) of Avoiding behaviour **(AB)(d)**. **(AB)(a)** refers to a scenario where an *individual human avoids another individual during the movement*. **(AB)(b)** refers to a scenario where an *individual avoids a group of individuals during the movement*. **(AB)(c)** refers to a scenario where a *group of individuals avoids an individual during*

the movement and **(AB)(d)** refers to a scenario where a *group of individuals avoids another group of individuals during the movement.*

The movement scenario and behaviour pattern of Passing Through behaviour is shown in Table 4.7. In this scenario another individual can be in a static or dynamic condition. The behaviour pattern is known as Pattern (a) of Passing Through behaviour **(PT)(a)**, Pattern (b) of Passing Through behaviour **(PT)(b)**, Pattern (c) of Passing Through behaviour **(PT)(c)** and Pattern (d) of Passing Through behaviour **(PT)(d)**. **(PT)(a)** refers to a scenario where an *individual human passing through another individual during the movement.* **(PT)(b)** refers to a scenario where an *individual passing through a group of individuals during the movement.* **(PT)(c)** refers to a scenario where a *group of individuals passing through an individual during the movement* and **(PT)(d)** refers to a scenario where a *group of individuals passing through another group of individuals during the movement.*

Table 4.7 Human movement scenario and Passing Through behaviour pattern

No	Human Movement (Scenario)	Description (Rules)	Behaviour (Pattern)
1.		Individual subject F passing through individual subject E	Passing Through behaviour (PT)(a)
2.		A group consist of subject A, B, C and D passing through individual subject K	Passing Through behaviour (PT)(b)
3.		Individual subject K passing through a group consist of subject	Passing Through behaviour (PT)(c)
4.		A group consist of subject K, L, M and N passing through a group consist of subject A, B, C and D	Passing Through behaviour (PT)(d)

4.4 Human Movement and Behaviour Analysis Using Observational Supporting Software and Observational Database

After the human movement and behaviour in the crowded area was recorded, the analysis of the video was conducted and the process involved is shown in Figure 4.10. The video analysis starts with selecting the recorded video. In this research, six hours of video was recorded and each video was considered as a different session. After the video was selected, the video was viewed for 30 seconds for every video frame using the observational supporting software (discussion on the observational supporting software and observational database is conducted in Section 4.4.1 and 4.4.2). 30 seconds of video frame was considered as a manageable time for analysis whilst avoiding any confusion.

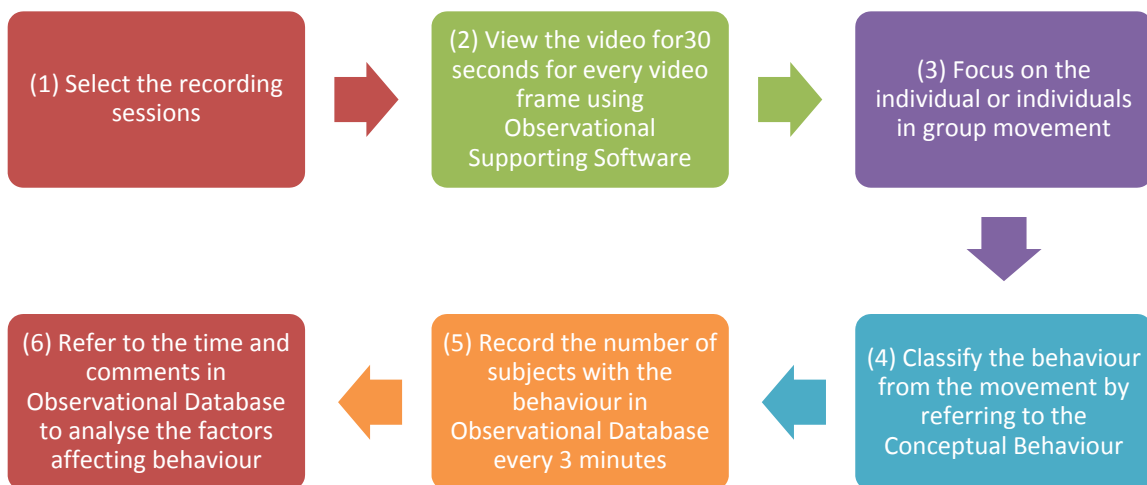


Figure 4.10 *The human movement and behaviour analysis process*

Each individual in the 30 seconds of video frame was observed manually one by one. The focus was on the types of movement performed. In this research, the movement of individuals was limited or simplified into free, same and opposite direction movement as discussed in the conceptual behaviours. By focusing on the types of movement, the type of behaviour performed by

the individual can be classified. The time when the behaviour was performed and any comments related to the movement or behaviour was recorded in the observational database.

During the process of recognising the movement and classifying the behaviour, the conceptual behaviour was referred to as a document to assist the observation analysis. The process of observing and recording the individual with their behaviour was conducted every 3 minutes. After 3 minutes, the number of individuals observed was counted in the observational database. Since the manual observation is considered to be a tedious process, the 3 minutes allocated for every session were considered to be a manageable time in order to maintain the focus during the observation analysis.

The process of analysing the human movement and behaviour for each recorded video was conducted until the end of the video (one hour for one recorded video). After all recorded videos were analysed, the behaviours are referred again to understand the factors affecting human movement and behaviour or other related findings. The factors affecting human movement and behaviour were based on the similarity of the movement and behaviour or similar events or scenarios that occurred in the video. Picture snapshots (from the video) are used to help the process and a detailed discussion will be conducted in Section 5.2.

4.4.1 Observational Supporting Software

Observational supporting software was used in this research to assist the observational analysis. Two types of software were selected and these are known as Windows Live Movie Maker Project and Windows Media Player as shown in Figure 4.11 and 4.12. Windows Live Movie Maker Project was selected because the software has a function to review the recorded video at any desired speed or arbitrary sequence (real-time, slow motion, fast motion, or frame-by-frame in either forward or reverse direction). Windows Media Player was also used because it is able to view the recorded video at a larger size.

The observational supporting software was also used to analyse the high density crowd in the recorded video. During the video analysis, the crowd density was different at several times and at some time frames the crowd density was considered to be high. Therefore, during the analysis there was a need to analyse the same video frame many times. Also, when the crowd density was considered high, the humans in a particular video frame performed more than one behaviour at one time within the observation area.

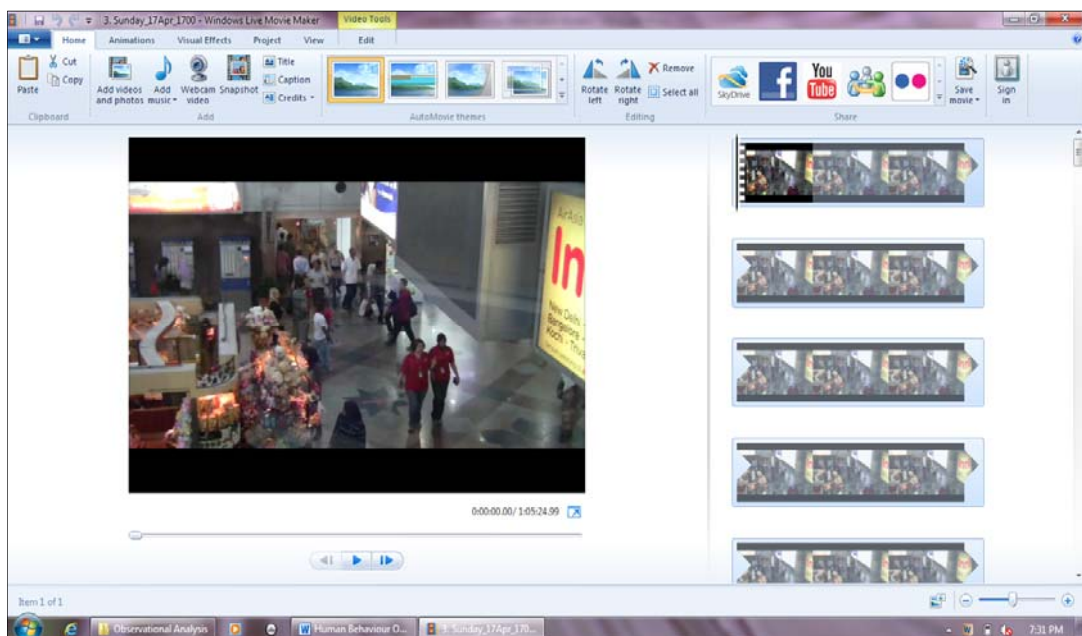


Figure 4.11 *Windows Live Movie Maker Project screen shot*

In this case, the behaviour was counted only once based on the first behaviour that appeared in the recorded video. For example, there were humans moving in a free direction and performing the Move-Stop-Move behaviour. However, when suddenly the crowd number was increased other humans were observed to move from the opposite direction of the first human. The situation caused the first human to perform another behaviour such as Avoiding behaviour. In this example, only Move-Stop-Move behaviour was counted and the number of humans involved was recorded in the observation database.

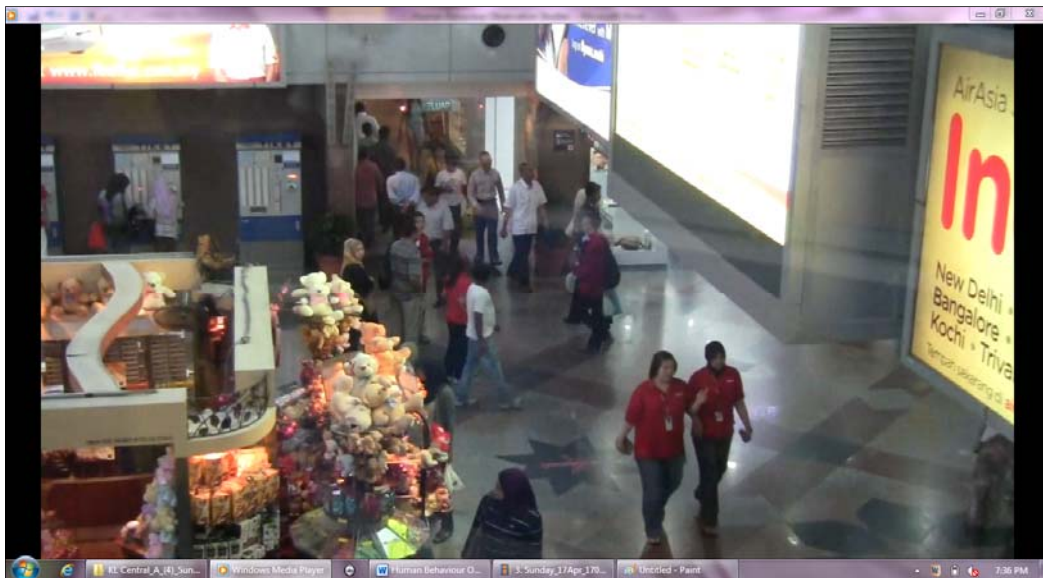


Figure 4.12 Windows Media Player screen shot

4.4.2 Observational Database

The observational database is a set of data consisting of information regarding individual human behaviours that were observed and analysed using the video observational supporting software based on the conceptual behaviour. Figure 4.13 shows the top area of the observational database that was developed based on the Excel spread sheet. The observational database was divided into six sections representing the total of six hours video recording sessions conducted.

Each section was recorded with the day, date and the recording starting time. Figure 4.8 for example shows the recording time for Sunday, 17 April 2011 and the recording was started at 5pm (17:00 hours).

In each recording session area (sections in the Excel spread sheet), a colour code system was applied to differentiate different the behaviour and behaviour patterns that were selected from the conceptual behaviours (e.g. yellow for Move-Stop-Move and green for Avoiding behaviour as shown in Figure 4.13). Next, in each behaviours section four sections for four subjects (the older people, people with disabilities, adult and others) were allocated. After the recorded video was analysed using the software, the number of subjects observed is recorded manually in the spread sheet based on the behaviour performed by the subject. As a future reference the time when the behaviour occurred was included in the database.

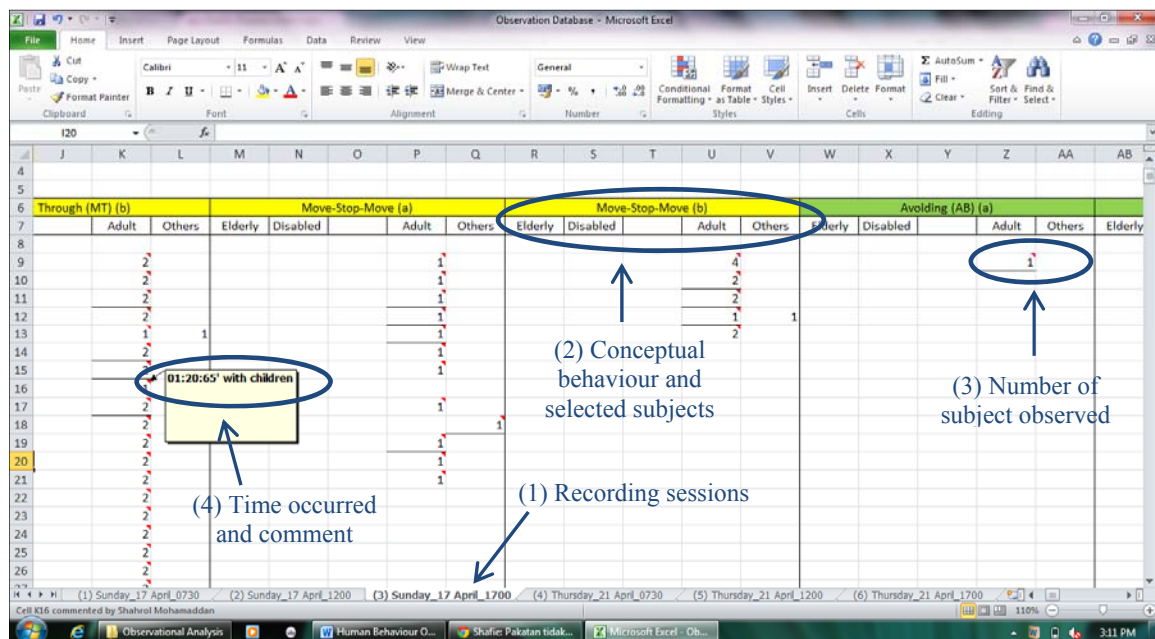


Figure 4.13 Overview of the top area of observational database

Figure 4.14 shows the bottom area of the observational database. Since the observational analysis was conducted every 3 minutes, the total number of humans that performed any behaviour was counted after the 3 minutes. Figure 4.14 shows an example of analysis that was conducted in

from minute 57 to 60 for the selected video. After the selected video was analysed until the end of the video (60 minutes), the total number of subjects for one specific conceptual behaviour was counted. Figure 4.14 shows an example where on the Sunday, 17 April 2011 video there were 147 humans observed performing the Move-Stop-Move behaviour (Pattern (a)). Lastly, the total number of subjects observed in one recording session was accumulated and Figure 4.14 shows that there were 3,254 humans observed within the recorded video. The total number of humans observed in the six hours video recording is discussed in the next chapter.

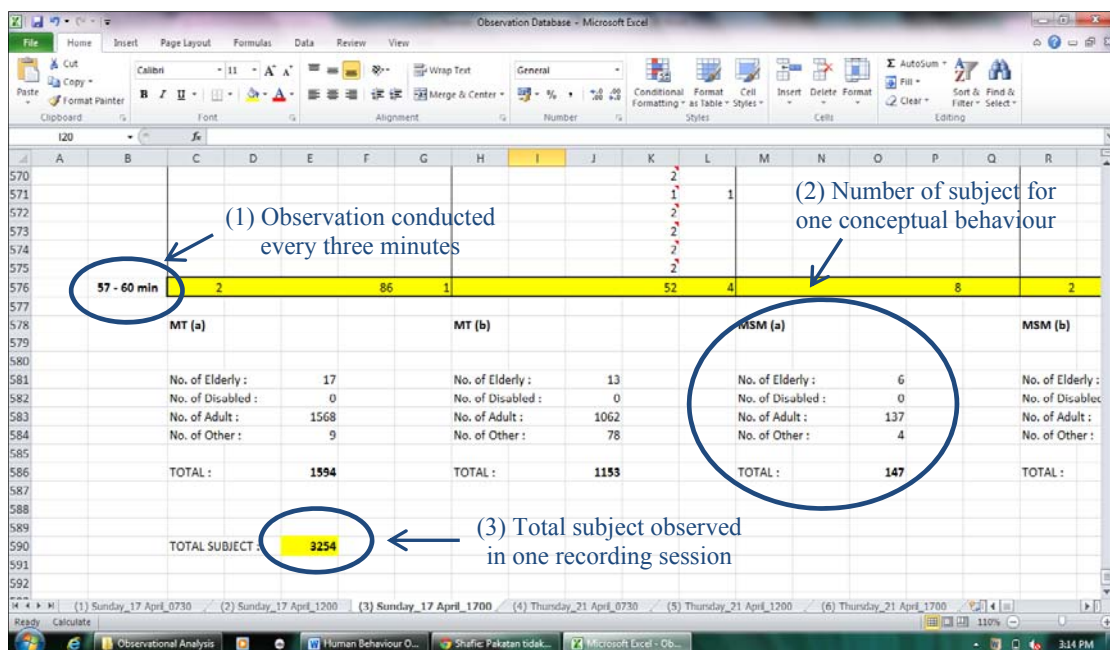


Figure 4.14 Overview of the bottom area of observational database

4.5 Summary

This chapter discussed the process of applying the video observational method in understanding human movement and behaviour within crowded areas. The method was considered as an excellent tool for analyzing 'real' human movement and behaviour within crowded areas. However, there is difficulty in understanding and classifying human movement and behaviour in the recorded video using the naked eye. Also, there was no contact or direct communication with the individual in the recorded video.

Therefore, conceptual behaviours were developed as a framework to help in understanding human movement and behaviour in crowds from the recorded video. The conceptual behaviours used a set of behaviour rules or codes that were constructed based on human movement in free, opposite and same directions. In order to avoid any exclusion of the movement and behaviour and to assist the analysis process, different types of behaviour pattern were developed based on the prediction of different types of movement scenario.

Conceptual behaviours alone are still considered to be difficult when trying to understand human movement and behaviour from the recorded video since human movement is considered to be dynamic and affected by many factors such as different speeds of movement, crowd density, etc. The recorded video needs to be analyzed by capturing the movement frame-by-frame, slow motion and can be replayed when required. In this research, supporting software Windows Live Movie Maker Project and Windows Movie Maker was selected to perform the important task.

The observational database was also developed to assist the analysis process. The database contains individual human data that was manually entered based on an understanding of human movement and behaviour using conceptual behaviour that was captured using the software. The development of the observational database is considered to be a tedious process. However,

considerable insight was gained from the process and it gives easy access to the individual human movement and behaviour data for further reference and analysis.

The video observational analysis process conducted in this chapter plays a vital role in understanding the 'real' human movement and behaviour. It can be considered as new contribution towards knowledge although it can be improved for other developments in the future. In the next chapter, the application of the analysis process is presented using the six hours of recorded video. The analysis will show the number of individual humans according to their subject with movement and behaviour involved. The next chapter also discusses the insight gained from the analysis conducted.

Chapter 5: Video Observational Results and Discussion

This chapter presents the results from the video observational studies conducted in Chapter 4. The results focus on the number of humans observed with the movements and behaviours performed in each recording session. The discussion is also conducted to understand the factors affecting human movement and behaviour in crowded areas based on video frames taken from the recorded video and also from the literature survey. The discussion provides an insight regarding the human movement and behaviour mechanism from the video observational studies.

5.1 Discussion on Video Observational Results

The results of video observational studies conducted in Chapter 4 are shown in Table 5.1 and Figure 5.1. In total 18,946 individuals were observed within six hours of video recording. Higher numbers of human were observed during weekdays (58.8% or 11,138 individuals) compared to weekends (41.2% or 7,808 individuals). In both recording sessions, more individuals were observed during the afternoon session (12 pm to 1 pm) compared to the morning session (7:30 am to 8:30 am) especially on the weekend where only 1,152 individuals were observed. The results indicate that activities within the observation area started relatively late, especially during the weekend.

Table 5.1 Video observational studies result

Recording session	Number of subject	
	17 April 2011 (Weekend)	21 April 2011 (Weekday)
Morning (7:30 am – 8:30 am)	1,152	3,020
Afternoon (12:00 pm – 1:00 pm)	3,402	4,182
Evening (5:00 pm – 6:00 pm)	3,254	3,936
Total subjects	7,808	11,138
Grand Total Subjects	18,946	

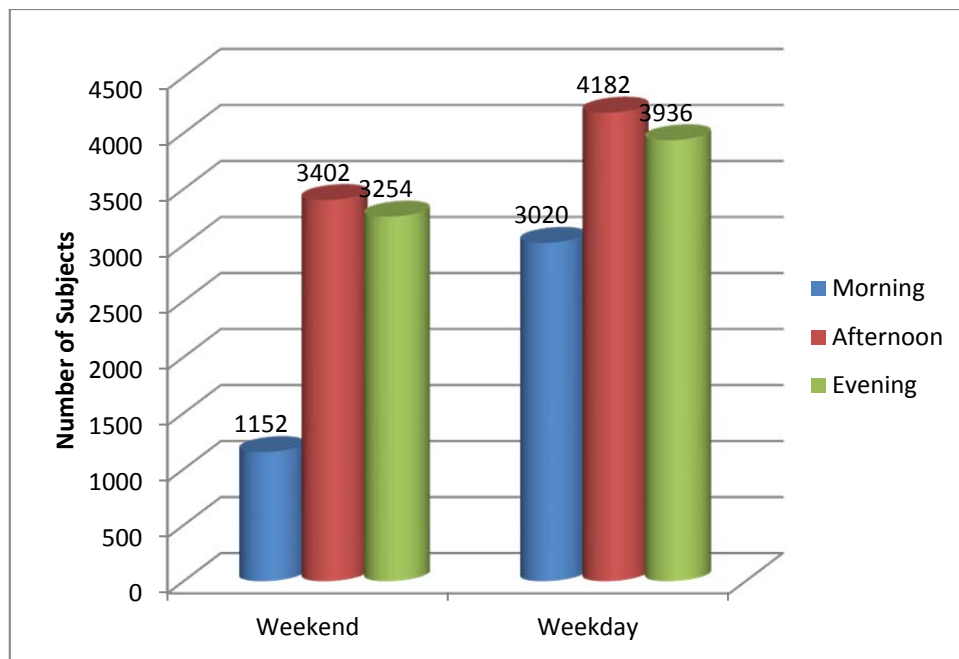


Figure 5.1 Number of subjects by recording session

Table 5.2 shows the human behaviour based on the movement of subjects. Within the 18,946 humans observed, the majority of the behaviours were observed during the free direction movement where 83.7% or 15,863 humans performed Moving Through behaviour and 10.2% or 1,929 humans performed Move-Stop-Move behaviour. Since most of the humans had free movement, the humans in the crowd were considered to have had enough space to move without facing any obstacle or constraint during the movement. The results show that the observation area

can be considered to have a low crowd density during the observation time and that the majority of the humans could maintain their personal space.

Besides free direction movement, 0.9% or 164 humans performed Queuing behaviour and 0.5% or 101 humans performed Competitive behaviour. The Queuing and Competitive behaviours were derived from the conceptual behaviour of same direction movement. Another 3.2% or 609 human performed Avoiding behaviour and 1.5% or 280 humans performed Passing Through behaviour. The Avoiding and Passing Through behaviour were derived from the conceptual behaviour of opposite direction movement.

Table 5.2 Human behaviour based on movement of subjects

No.	Behaviour	No. of Older People	No. of People with Disabilities	No. of Adults	No. of Others	TOTAL
<i>Free Direction Movement</i>						
1.	Moving Through (MT)	268	15	15,192	388	15,863
2.	Move-Stop-Move (MSM)	71	1	1,770	87	1,929
<i>Same Direction Movement</i>						
3.	Queuing behaviour (QB)	1	0	162	1	164
4.	Competitive behaviour (CB)	2	0	98	1	101
<i>Opposite Direction Movement</i>						
5.	Avoiding Behaviour (AB)	13	0	588	8	609
6.	Passing Through Behaviour (PT)	14	0	248	18	280
TOTAL		369	16	18,058	503	18,946

Although the observation process attempted to cover various recording times so as to record a diversity of subjects, the number of older people and people with disabilities within the six hours of video recording was very low. The older people and people with disabilities were only 2% of the total subjects. Adults were most frequently observed and they comprised 95.3% of the subjects

while others were 2.7% of the total. The small number of older people and people with disabilities within the observation area might have occurred due to several factors.

One of the factors that can be considered is the different attitude of older people and people with disabilities in Malaysia towards journeying in crowd. In Malaysia, the older people and those with disabilities tend to spend more time at home and do not expose themselves to the public. It is difficult to observe older people and those with disabilities travelling alone in Malaysia when compared to other advanced countries like the UK and Japan. The situation is not considered as a cultural issue but rather a reflection on the advancement in public services and facilities design that can support these people. Public services and facilities design that are more accessible and user-friendly ensure that more safe journeys can be made which can increase the self-esteem of older people and those with disabilities that travel alone. The ultimate objective for this research is to support those objectives.

Based on the observation results, people with disabilities were only observed performing free direction movement. There were no people with disabilities observed performing the opposite direction and same direction movement. The older people were observed more in free direction movement especially on Moving Through behaviour. The behaviours shown in Table 5.2 were developed based on the accumulation of different types of behaviour patterns. Some of the behaviour might be applicable in the real world and some might not be applicable. The distribution of the behaviours according to behaviour pattern is discussed in the next sub-section.

5.1.1 Moving Through Behaviour Subjects

Table 5.3 and Figure 5.2 show the distribution of Moving Through behaviour based on behaviour pattern and subjects (a detailed discussion about the behaviour pattern was conducted in

Section 4.4.1). In total there were 15,863 individuals observed performed the Moving Through behaviour and 68% or 10,714 individuals performed Moving Through Behaviour Pattern (a), **(MT)(a)** and 32% or 5,149 individuals performed Moving Through Behaviour Pattern (b), **(MT)(b)**. Adults were the highest number of subjects performing the behaviour with 95.8% or 15,192 individuals. It follows that there were 2.4% or 388 ‘others’ and 1.7% or 268 older individuals. Only 0.1% or 15 individuals people with disabilities was observed performed Moving Through behaviour.

Table 5.3 *Observational result of Moving Through behaviour*

Behaviour Pattern	No. of Older People	No. of People with Disabilities	No. of Adults	No. of Others	TOTAL
Moving Through behaviour (MT)(a)	186	14	10,398	116	10,714
Moving Through behaviour (MT)(b)	82	1	4,794	272	5,149
TOTAL	268	15	15,192	388	15,863

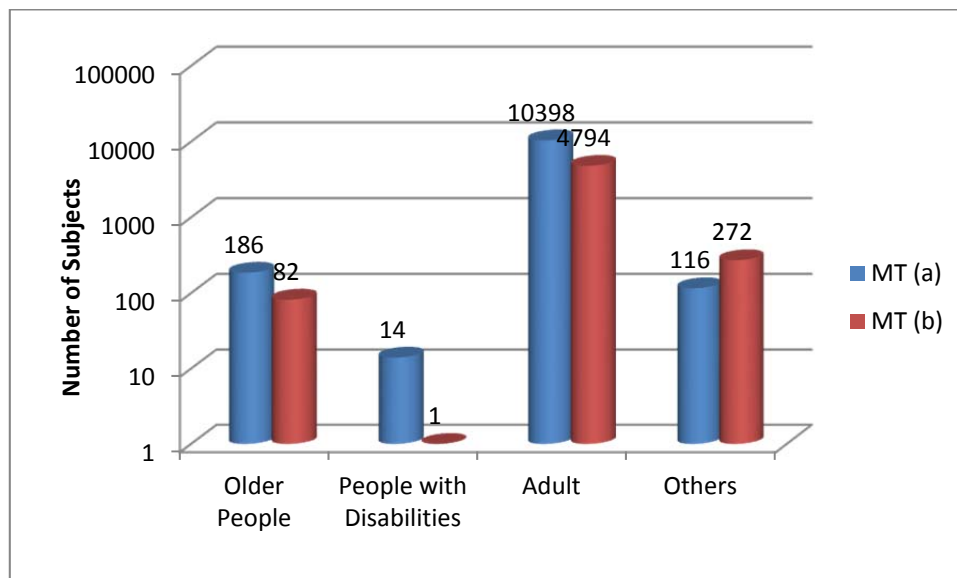


Figure 5.2 *Moving Through behaviour (MT) based on behaviour patterns and subjects*

Figure 5.3 shows an example of the Moving Through behaviour pattern using a video frame taken from the weekend video (17 April 2011, start 7:30 am). The frame shows an individual (MT)(a) and individuals in group (MT)(b) moving through the observation area without any specific concern or facing any obstacle. During that particular time, the crowd density was very low and it is easier to observe the subjects. Based on the video analysis, different types of activities can be observed being performed by the Moving Through behaviour subjects such as using a mobile phone, listening to music or reading a newspaper. There were also subjects making a turn or changing direction (without stopping) during the movement.



Figure 5.3 *Moving Through behaviour for individual and group movements*

There was no specific concern related to the Moving Through behaviour subjects since the movement and behaviour are considered to be simple, straight forward and well understood. However, a differences a can be observed between Moving Through behaviour subjects in the gap of movement between the individuals in a group and the different speeds of movement among the

subjects as shown in Figure 5.4 and 5.5. Figure 5.4 shows that the gap of movement between individuals in a group is slightly wider compared to the group in Figure 5.3. In this case, individuals in a group were recognized by their physical appearance when the entire group members were using the backpack.

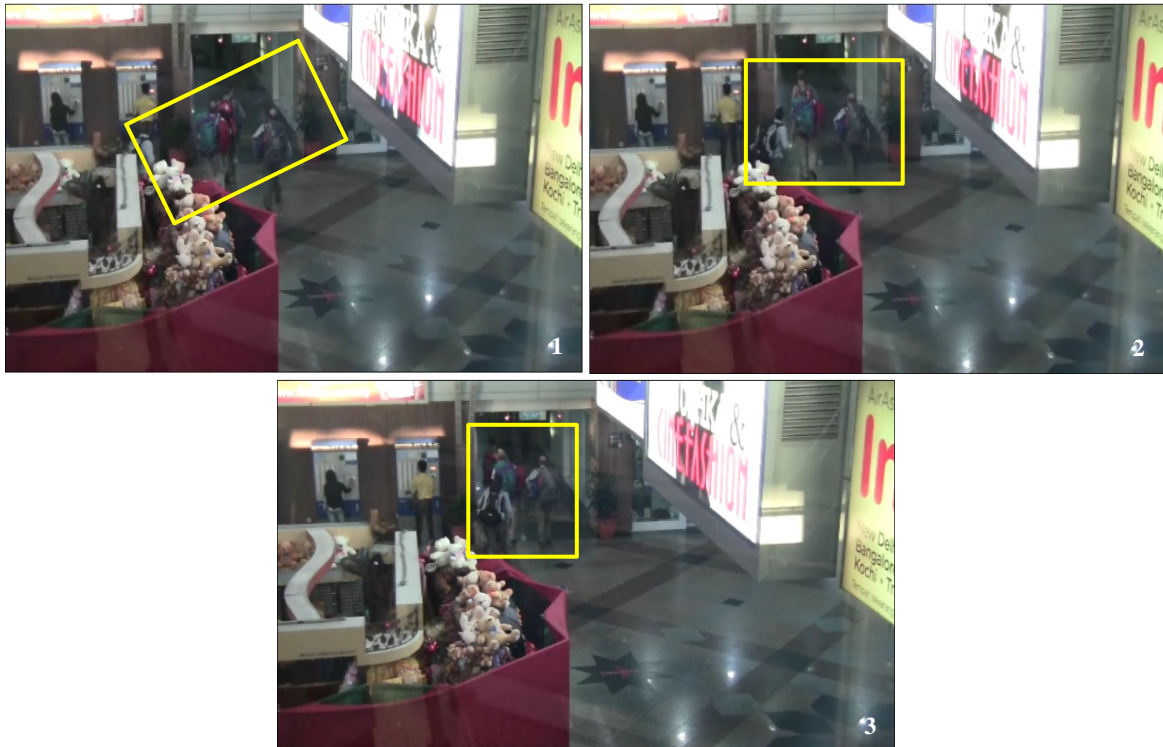


Figure 5.4 *Gap between the groups in Moving Through behaviour*

In Figure 5.5, subjects with different speeds of movement can be observed by the size of step taken during the movement. The gap between individuals in group and speed of movement were important phenomena that should be considered and well analysed since it can affect the video analysis process. For example, if the gap in movement is not considered during the analysis process the individuals in a group will be counted as different entities. For the case of different speed of movement, a higher speed of movement can produce different types of behaviour such as Competitive behaviour.

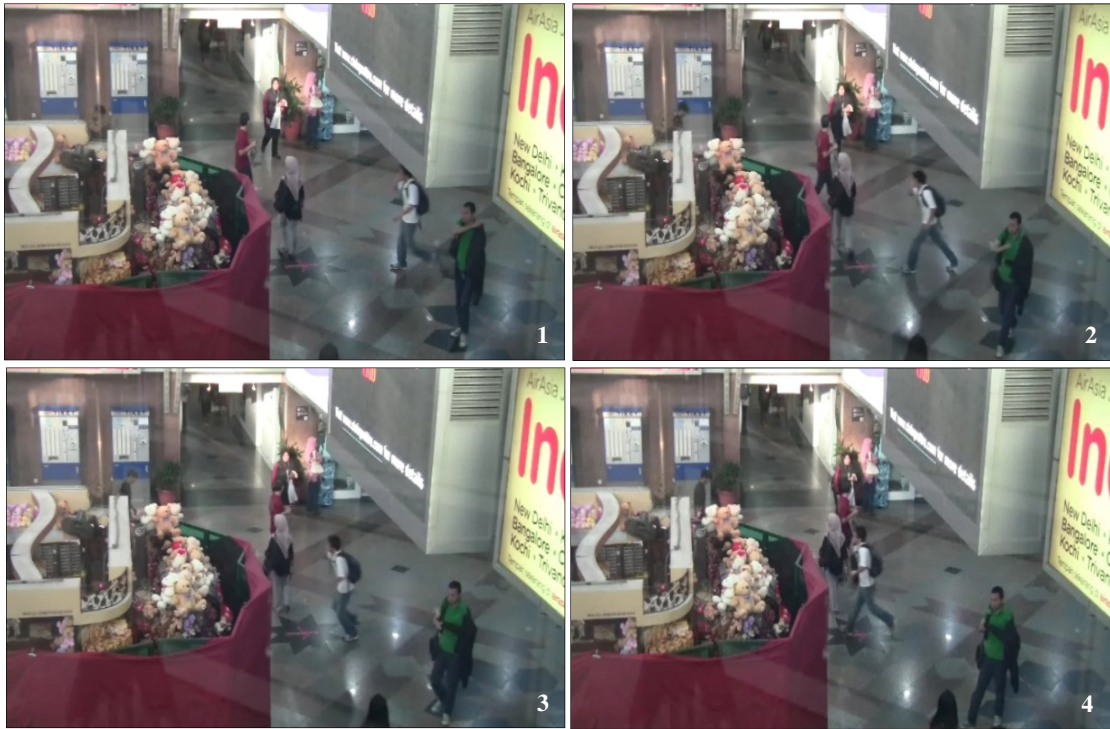


Figure 5.5 *Different speed of movement in Moving Through behaviour*

5.1.2 Move-Stop-Move Behaviour Subjects

Table 5.4 and Figure 5.6 show the distribution of Move-Stop-Move behaviour based on behaviour patterns and subjects (a detailed discussion of behaviour patterns was provided in Section 4.4.1). In total there were 1,929 individuals observed performing the Move-Stop-Move behaviour within the six hours of video recording. 42.7% or 823 individuals performed the Move-Stop-Move Behaviour Pattern (a), **(MSM)(a)** and 57.3% or 1,106 individuals performed the Move-Stop-Move Behaviour Pattern (b), **(MSM)(b)**. Adults were the largest group of subjects performing the behaviour with 91.76% or 1,770 individuals. 4.5% or 87 were ‘others’ and there were 3.68% or 71 older people. Only 0.06% or 1 individual from the older subjects performed the Move-Stop-Move behaviour.

Table 5.4 *Observational result of Move-Stop-Move behaviour*

Behaviour Pattern	No. of Older People	No. of Disabled	No. of Adults	No. of Others	TOTAL
Move-Stop-Move behaviour (MSM)(a)	23	1	788	11	823
Move-Stop-Move behaviour (MSM)(b)	48	0	982	76	1,106
TOTAL	71	1	1,770	87	1,929

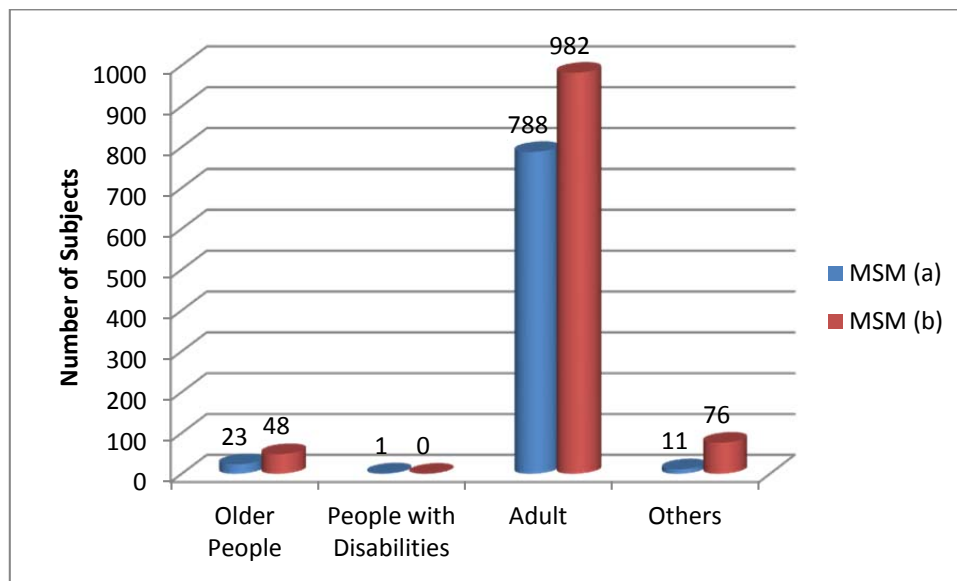


Figure 5.6 *Move-Stop-Move behaviour (MSM) based on behaviour patterns and subjects*

Figure 5.7 shows a video frame of a Move-Stop-Move behaviour pattern taken from the weekday video (21 April 2011, start 7:30 am). The image shows that there was a man and individuals in a group consisting of two women performing the Move-Stop-Move behaviour (highlighted with arrows). Video analysis shows that the man and the women were moving around and stopping at the location, looking to find something or somebody. A few times were taken to perform the Move-Stop-Move behaviour and it was represented by the movement of the woman with luggage highlighted in the yellow oval. The lady was observed moving through the

observation area from frame 1 until frame 4. However, the man and the women were still standing at the same location.

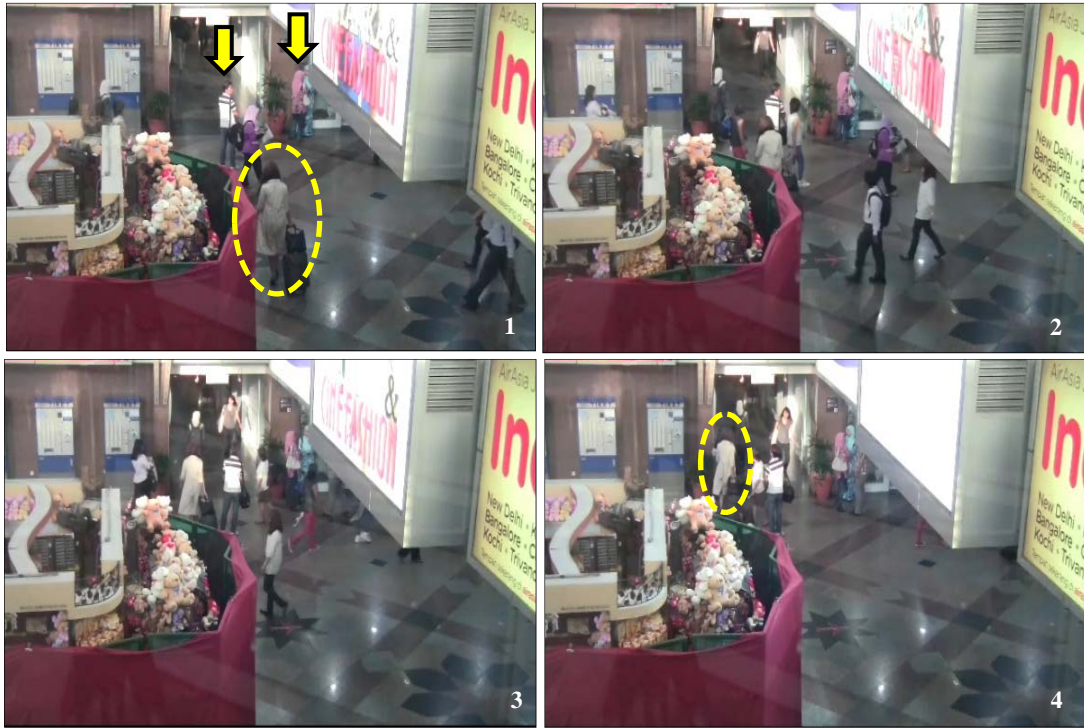


Figure 5.7 Sequential images showing the Move-Stop-Move behaviour
(Left to right, from top to bottom)

Figure 5.8 shows the video frame of a Move-Stop-Move behaviour taken from the weekday video (21 April 2011, start 7:30 am). Three different subjects performed the Move-Stop-Move behaviour within the frame. The first subject was the man moving with red luggage (highlighted with yellow arrow). In frames 1 and 2, the subject was observed moving from the left to the right side of the observation area. However, in frame 3 the subject was observed making a stop for a while and looking for information at the exit door. The subject then changes direction towards the exit door in frame 4 and makes another stop in frame 5. In frame 6, the subject changed direction again and continued the journey in frame 7 and 8. This time the movement was similar to the earlier planned route.



Figure 5.8 Sequential images showing the Move-Stop-Move behaviour (21 April, 7:30 am)

The second subject was the man at the ticket machine (highlighted in white oval in frame number 1). The man was observed making a stop at the ticket machine to buy a ticket. This was an example of activity performed by the Move-Stop-Move behaviour subjects. In the frame, the man was seen several times buying a ticket since he can be observed from frame 1 until frame 8 of the

picture. The third subject performing the Move-Stop-Move behaviour was the older woman that was observed from the frame 3 until frame 8 of the picture (highlighted by a green arrow in frame 3). The subject was observed making a movement in frames 3 and 4. However, the subject makes a stop in front of the exit door. Based on video analysis, the subject was considered to be looking at the information located at the exit door.

Figure 5.8 indicates that Move-Stop-Move behaviour subjects have different stopped times during the movement. The stop time was shorter or longer depending on the activity. Buying a ticket at the ticket machine and looking for information were examples of tasks performed by the Move-Stop-Move behaviour subjects. It also indicated that information regarding the place, services and etc. is important for the humans especially those who are using the facilities for the first time.

5.1.3 Queuing Behaviour Subjects

Table 5.5 and Figure 5.9 shows the distribution of Queuing behaviour based on subjects and behaviour pattern (a detailed discussion of the behaviour pattern was conducted in Section 4.4.2). In total 164 individuals were observed performed the Queuing behaviour within the six hours video recording. 95.7% or 157 individuals performed the Queuing behaviour Pattern (a), **(QB)(a)**, 4.3% or 7 individuals performed the Queuing behaviour Pattern (b), **(QB)(b)** and there were no subjects observed performed the Queuing behaviour Pattern (c), **(QB)(c)** and Queuing behaviour Pattern (d), **(QB)(d)**. Adults were the most frequently observed subjects performing the Queuing behaviour with 98.8% or 162 individuals. Older people and others consisted of 1.2% or 1 individual each. People with disabilities were not observed performing the Queuing behaviour.

Table 5.5 *Observational result of Queuing behaviour*

Behaviour Pattern	No. of Older People	No. of People with Disabilities	No. of Adults	No. of Others	TOTAL
Queuing Behaviour (QB)(a)	1	0	155	1	157
Queuing Behaviour (QB)(b)	0	0	7	0	7
Queuing Behaviour (QB)(c)	0	0	0	0	0
Queuing Behaviour (QB)(d)	0	0	0	0	0
TOTAL	1	0	162	1	164

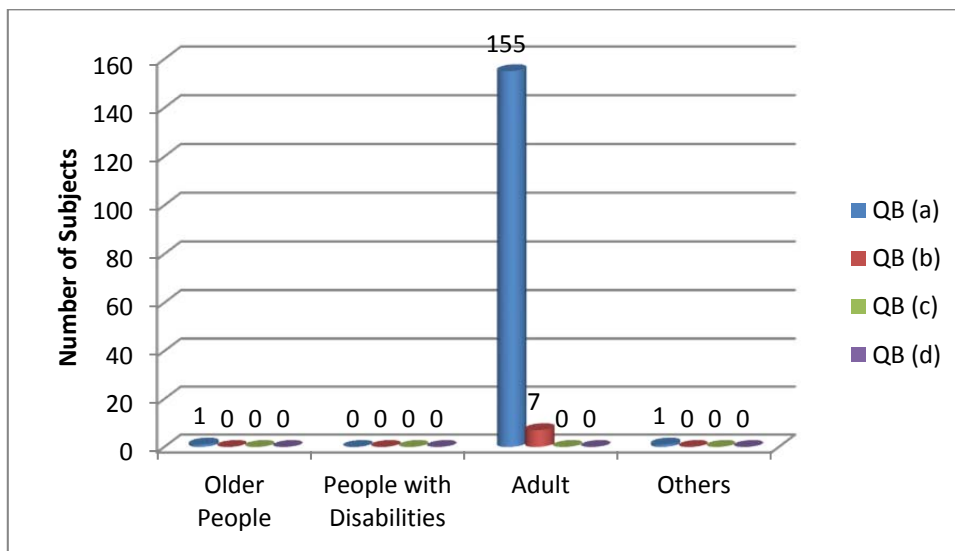


Figure 5.9 *Queuing behaviour (QB) based on behaviour patterns and subjects*

The Queuing behaviour was considered to be difficult to observe within the observation area. The main reason was that the movement of people within the observation area was very random. The subjects had no specific objective compared to a bottleneck exit where the behaviour can be easily observed due to the size of the bottleneck area. Most of the Queuing behaviour pattern within the recorded video was observed when there was a limited space for humans to move along the movement path. The limited space occurs because of the appearance of other objects or humans

in the middle of the pathway (e.g. a Move-Stop-Move behaviour subject becomes an obstacle to another subject).

Figure 5.10 shows an example of the Queuing behaviour pattern in a video frame taken from the weekend video (21 April 2011, start 12 pm). The frames show that there were three individuals queuing and moving in a row from frame 1 until frame 4. The subjects were also observed avoiding other subjects during the movement and while maintaining the queue. The observational study cannot determine the relationship between the subjects from the video. However, the subjects were observed having a similar characteristic which is carrying a bag during the movement. It could indicate that the subjects having a similar objective during the movement.

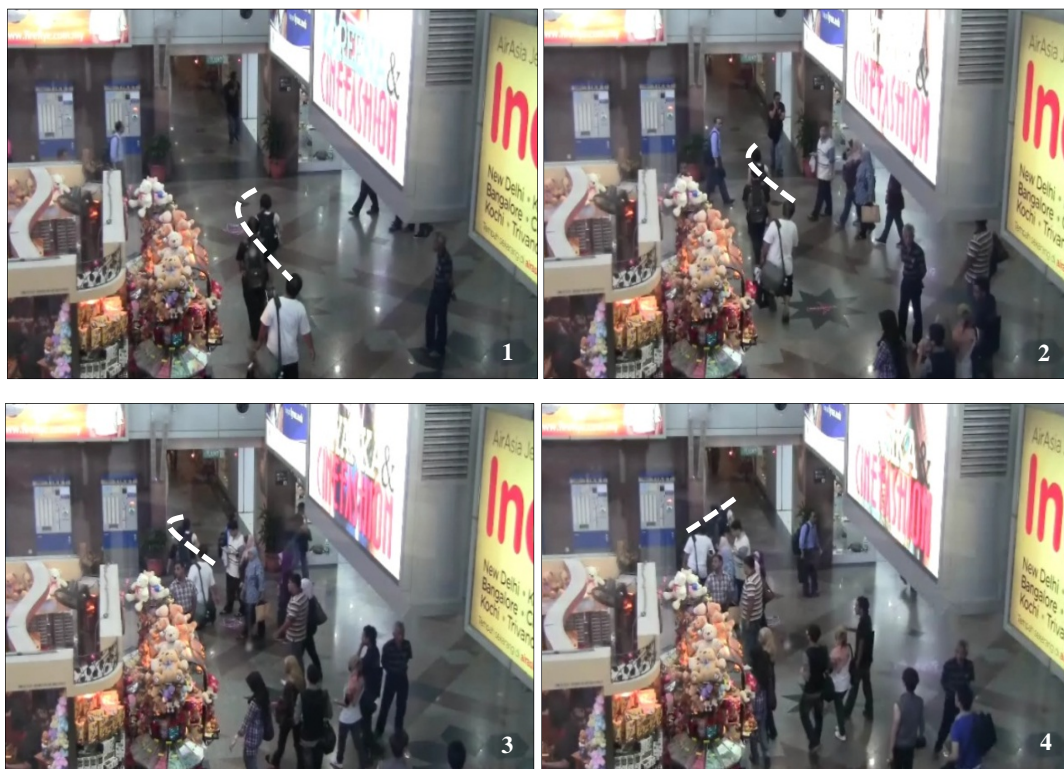


Figure 5.10 *Queuing behaviour subjects*

5.1.4 Competitive Behaviour Subjects

Table 5.8 and Figure 5.11 shows the distribution of Competitive behaviour based on subjects and behaviour pattern (a detailed discussion of the behaviour pattern was provided in Section 4.4.2). In total 101 individuals were observed performing the Competitive behaviour within the six hours of video recording. 62.4% or 63 individuals performed the Competitive behaviour Pattern (a), **(CB)(a)**, 30.7% or 31 individuals performed the Competitive behaviour Pattern (b), **(CB)(b)**, 6.9% or 7 individuals performed the Competitive behaviour Pattern (c), **(CB)(c)** and no individual performed the Competitive behaviour Pattern (d), **(CB)(d)**. Adults were the most frequently observed subjects performing the behaviour with 98% or 98 individuals. There were 2% or 2 older people and 1% or 1 ‘other’ person. People with disabilities were not observed performing the Competitive behaviour.

Table 5.6 *Observational result of Competitive Behaviour*

Behaviour Pattern	No. of Older People	No. of People with Disabilities	No. of Adults	No. of Others	TOTAL
Competitive behaviour (CB)(a)	1	0	62	0	63
Competitive behaviour (CB)(b)	1	0	29	1	31
Competitive behaviour (CB)(c)	0	0	7	0	7
Competitive behaviour (CB)(d)	0	0	0	0	0
TOTAL	2	0	98	1	101

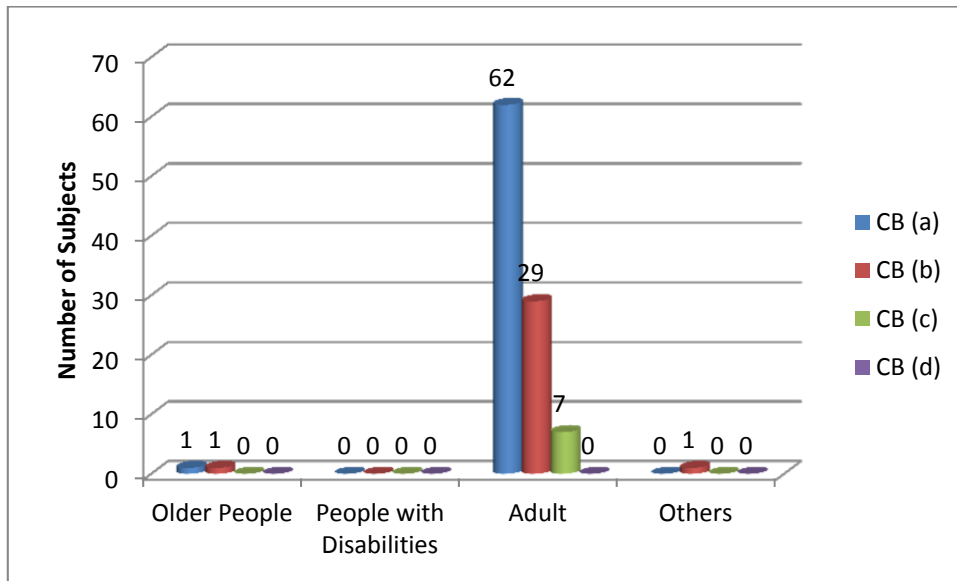


Figure 5.11 *Competitive behaviour (CB) based on behaviour patterns and subjects*

Figure 5.12 shows an example of Competitive behaviour in video frame taken from the recorded video. The subject (marked with an arrow) was moving in the same direction with a family consisting of two adults and one child. However, the family were observed moving slower compared with the subject. In order to move on the route planned earlier, the subject has to compete with the family in front. In that situation, the subject had to make an adjustment to the route to move faster. As shown in frame 3, the subject finally managed to move within the planned route earlier than the family.

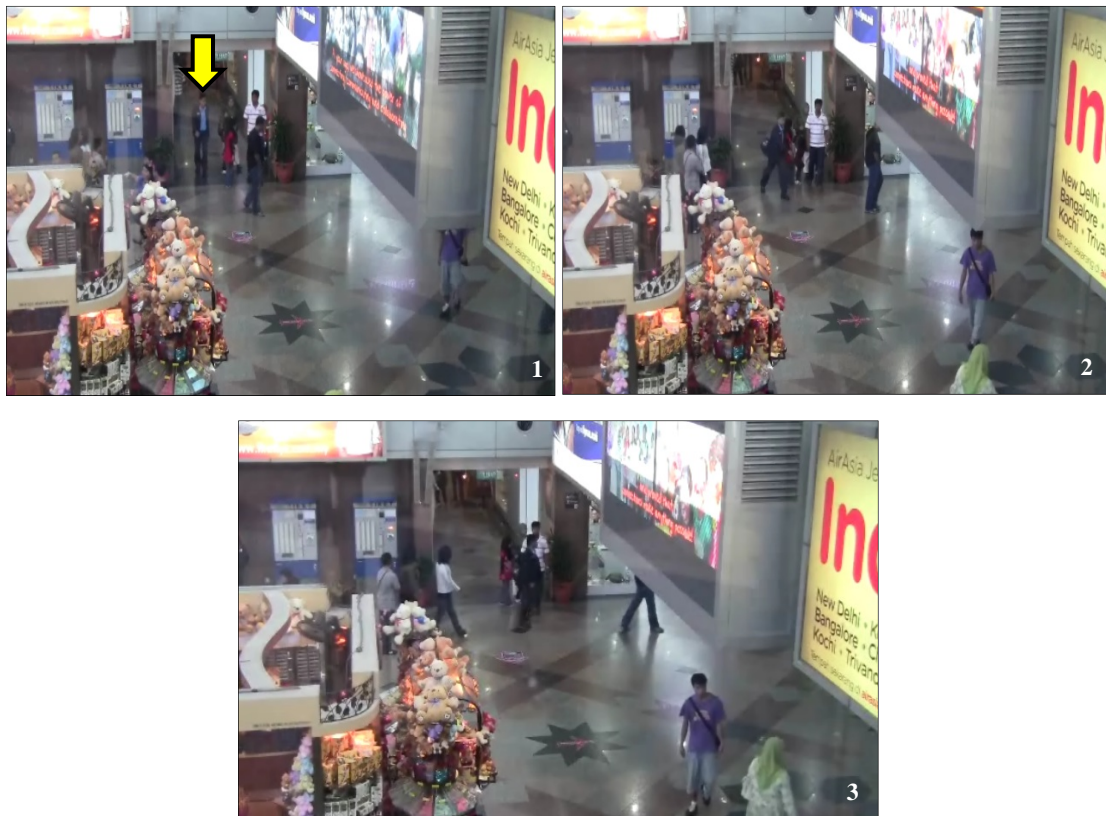


Figure 5.12 Competitive behaviour subjects

5.1.5 Avoiding Behaviour Subjects

Table 5.7 and Figure 5.13 show the distribution of Avoiding behaviour based on behaviour pattern and subjects (a detail discussion of the behaviour pattern was provided in Section 4.4.3). In total there were 609 individuals observed performing the Avoiding Behaviour within the six hours video recording. 44.2% or 269 individuals performed the Avoiding Behaviour Pattern (a), **(AB)(a)**, 13.8% or 84 individuals performed the Avoiding Behaviour Pattern (b), **(AB)(b)**, 19% or 116 individuals performed the Avoiding Behaviour Pattern (c), **(AB)(c)** and 23% or 140 individuals performed the Avoiding Behaviour Pattern (d), **(AB)(d)**. Adults were the most frequently observed subjects performing the behaviour with 96.6% or 588 individuals. There were 2.1% or 13 older people and 1.3% or 8 ‘others’. Disabled people were not observed performing the behaviour.

Table 5.7 *Observational result of Avoiding behaviour*

Behaviour Pattern	No. of Older People	No. of Disabled	No. of Adults	No. of Others	TOTAL
Avoidance behaviour (AB)(a)	2	0	266	1	269
Avoidance behaviour (AB)(b)	4	0	79	1	84
Avoidance behaviour (AB)(c)	5	0	106	5	116
Avoidance behaviour (AB)(d)	2	0	137	1	140
TOTAL	13	0	588	8	609

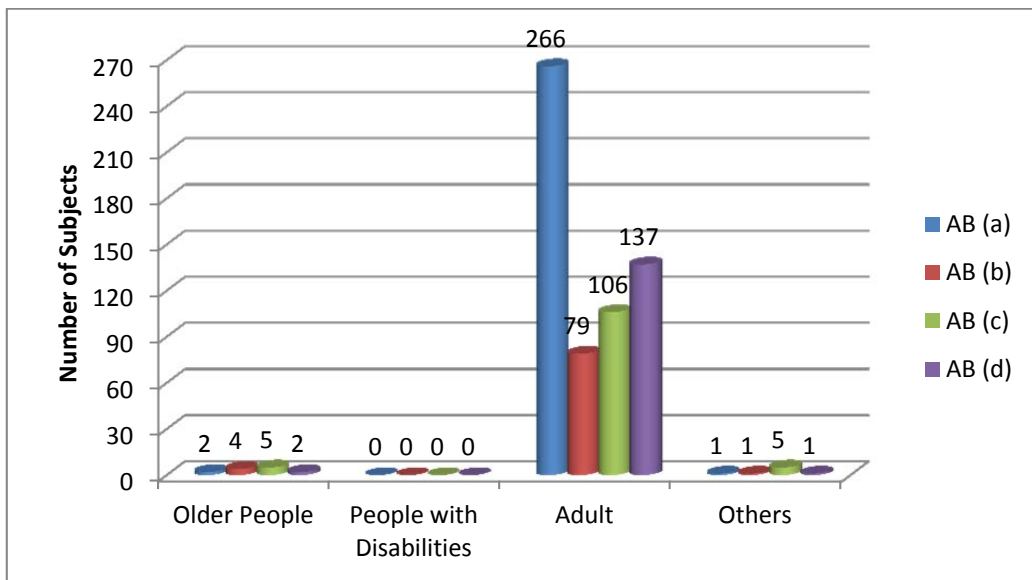


Figure 5.13 *Avoiding behaviour (AB) based on behaviour patterns and subjects*

Figure 5.14 shows an example of Avoiding behaviour from a frame taken from the weekend video (21 April 2012, start 7:30 am). The frames show a subject (highlighted in yellow) moving towards the exit door. At the middle of the planned route the subject meets with individuals in a group. The individuals were carrying a luggage during the movement. The frames show that the individuals in the group make a movement without considering the individual. In this case the

subject had to stop and find an avoiding route to avoid the individuals in the group as shown in frames 3 and 4.

Figure 5.14 also shows an example where Avoiding behaviour occurred together with Passing Through behaviour. It shows that the Avoiding behaviour is not dominant to get a way whilst ready to give way to others. The individuals with luggage or individuals in the group were observed to be more dominant in getting their own way by performing the Passing Through behaviour.

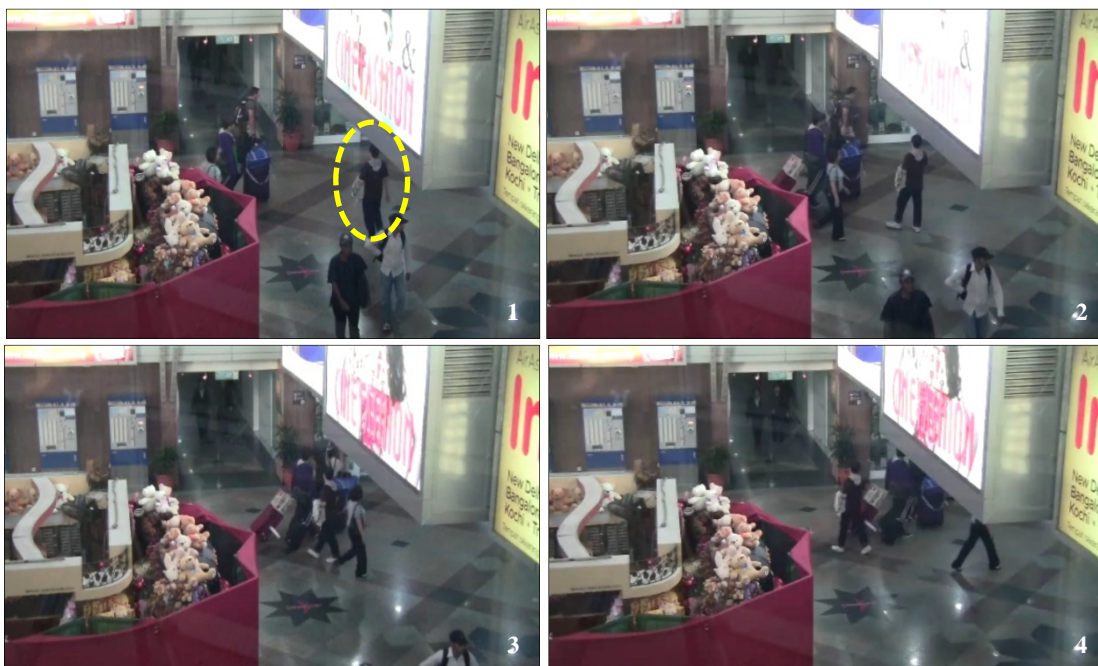


Figure 5.14 *Sequential images showing the Avoiding behaviour subjects*

5.1.6 Passing Through Behaviour Subjects

Table 5.8 and Figure 5.15 show the distribution of Passing Through behaviour based on behaviour pattern and subjects (a detailed discussion of the behaviour pattern was provided in Section 4.4.3). In total 208 individuals were observed performing the Passing Through behaviour within the six hours of video recording. Adults were most frequently observed performing the behaviour with 88.6% or 248 individuals. 6.4% or 18 ‘others’ and 5% or 14 older people were observed.

People with disabilities were not observed performed the Passing Through behaviour. 32.9% or 92 individuals performed the Passing Through Behaviour Pattern (a), **(PT)(a)**, 21.4% or 60 individuals performed the Passing Through Behaviour Pattern (b), **(PT)(b)**, 17.5% or 49 individuals performed the Passing Through Behaviour Pattern (c), **(PT)(c)** and 28.2% or 97 individuals performed the Passing Through Behaviour Pattern (d), **(PT)(d)**.

Table 5.8 *Observational result of Passing Through behaviour*

Behaviour Pattern	No. of Older People	No. of Disabled	No. of Adults	No. of Others	TOTAL
Passing Through behaviour (PT)(a)	5	0	86	1	92
Passing Through behaviour (PT)(b)	2	0	57	1	60
Passing Through behaviour (PT)(c)	0	0	42	7	49
Passing Through behaviour (PT)(d)	7	0	63	9	79
TOTAL	14	0	248	18	280

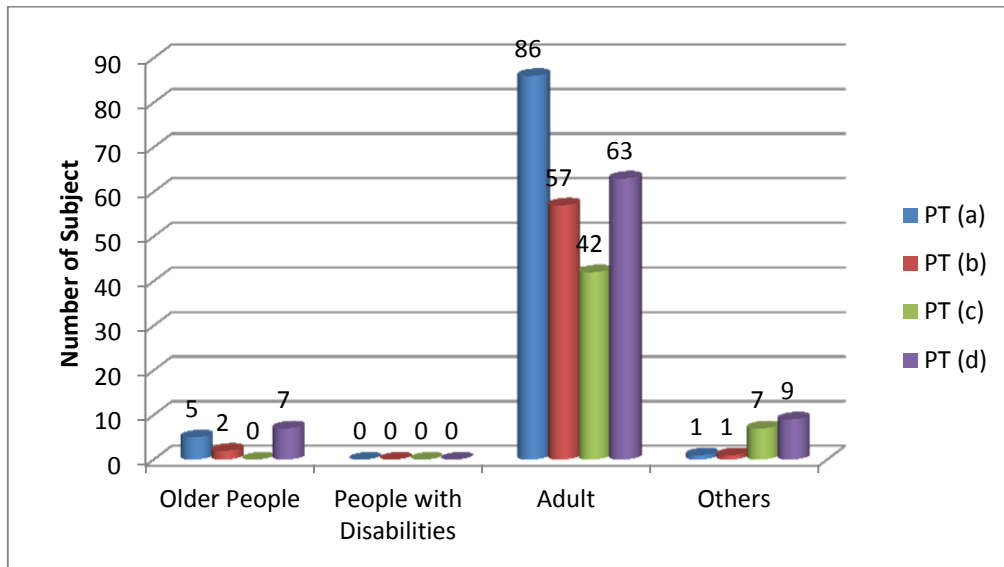


Figure 5.15 *Passing Through behaviour (PT) based on behaviour patterns and subjects*

Figure 5.16 shows an example of the Passing Through behaviour pattern performed by an individual subject from a frame taken from the weekday video. In the frames, the individual can be seen moving while reading a newspaper. Although there was a possibility of collision with other individuals as shown in frame 2, the subject was observed to have no concern about the situation and just makes the movement. The situation causes the other subject to stop and allow the subject to make the movement. After the subject had passed through, the other subject continued the movement on the planned route.

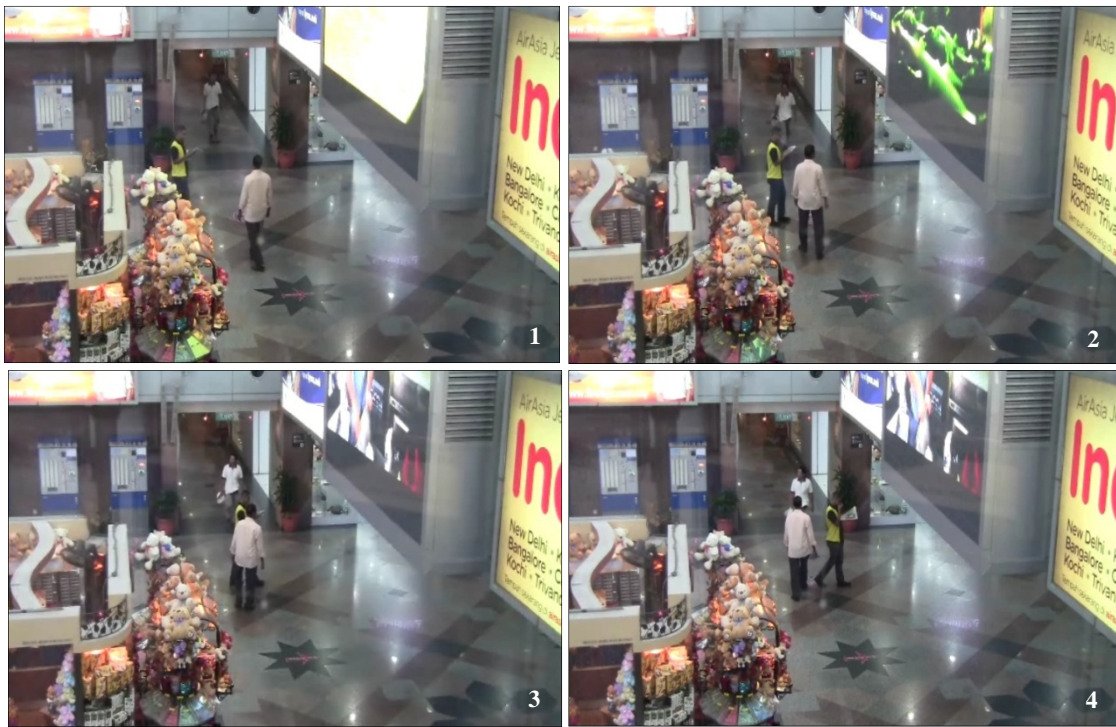


Figure 5.16 Sequential images showing the *Passing Through* behaviour subjects

5.2 Discussion on Factors Affecting Human Movement and Behaviour

Section 5.1 discussed the video observational results and analysis of human movement and behaviour based on behaviour patterns and subjects. The frames taken from the recorded video were used to analyse and validate the human movement and behaviour. Considerable insight was acquired from the video analysis including an understanding of the factors affecting human movement and behaviour in crowded areas.

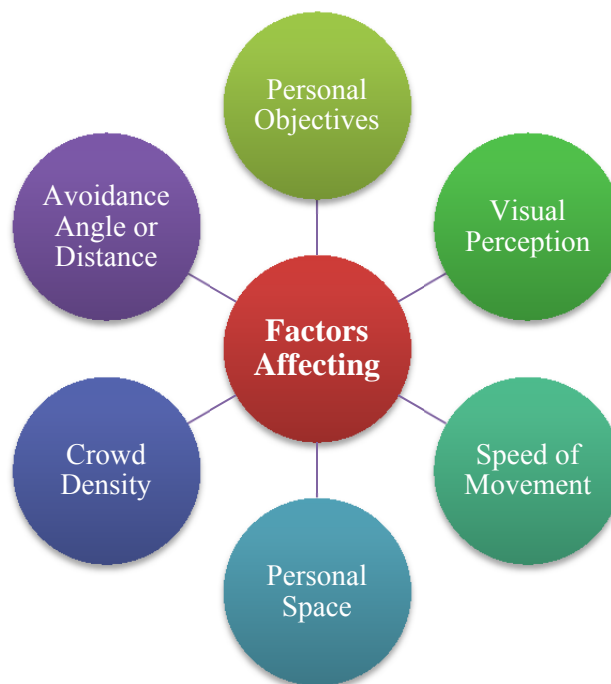


Figure 5.17 *Factors affecting human movement and behaviour in crowded areas*

Based on the six hours video observational analysis conducted, six factors were considered to be affecting human movement and behaviour within the crowded areas as shown in Figure 5.17. The factors are Personal Objective, Visual Perception, Speed of Movement, Personal Space, Crowd Density and Avoidance Angle or Distance. The factors affecting human movement and behaviour were considered based on the similarity of human movement and how the behaviour occurred during the video observational analysis. The factors considered were also supported by the literature survey of other research.

The factors affecting human movement and behaviour in crowds are important input for this research. The factors considered from the real world will be applied later as parameters for human movement and behaviour simulation in the virtual environment. A detailed discussion on assigning the factors from the real world as parameters in the virtual environment will be provided in Chapters 6 and 7. In this section the discussion is focused on the definition of the factors, examples taken from the video frames and supported arguments from the literature survey.

5.2.1 Personal Objective

Personal objective refers to the goal that humans have during movement. Personal objective is considered as the main factor that determines human decision making and behaviour during movement in crowded areas. Although there was no direct communication or contact with the subjects in the crowd, personal objectives can be observed based on the physical appearance or activities performed by the subjects within the recorded video. According to Daamen et al. (2002), different types of activities can be observed within the transfer station. Different types of behaviour such as Competitive and Queuing occurred based on different personal objectives (Pan et al. 2006).

The video observation showed that humans had different types of personal objectives. For example, during weekdays most people were observed wearing business suits because of the working day while during the weekend most people wore casual outfits. In the transportation area there were people journeying from one destination to another. This can be determined by observing people with luggage or backpacks, looking for information, approaching others with maps or documents, buying a ticket from a ticket machine and other activities. Figure 5.18 shows an example of people moving around with luggage and backpacks within the observation area (highlighted by a yellow box). The pictures were taken from different time sessions within the recorded video.

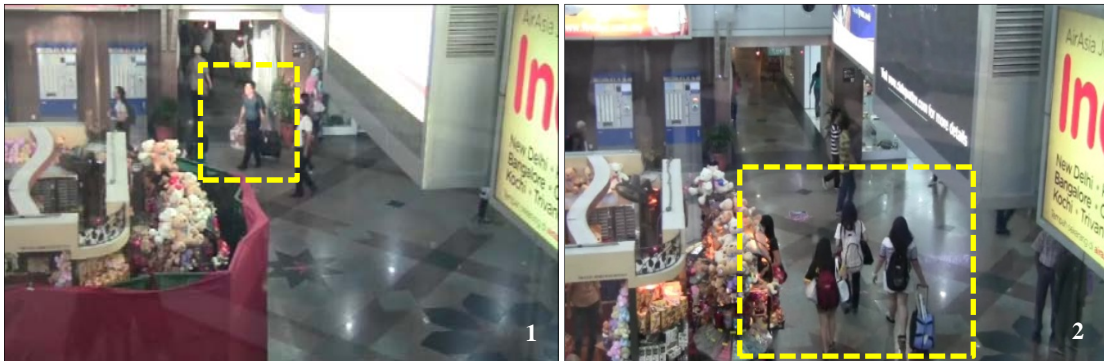


Figure 5.18 *The personal objective of the subjects*

Figure 5.19 shows another example of different activities performed by people within the crowd. The activities performed can represent the different personal objectives that people have and these affect movement and behaviour. Based on video observation there are at least five different personal objectives observed in Figure 5.19. There was a man talking on a mobile phone and buying a train ticket, the cleaner performing cleaning, individuals walking together in group or walking alone and individuals waiting or stopping during the movement. These are examples of each individual having their own personal objective during the movement.



Figure 5.19 *Different personal objectives within the crowd*

5.2.2 Visual Perception

Visual perception refers to the ability of humans to process and interpret information from the surrounding environment through their vision system. According to Ondřej et al. (2010), humans rely on visual perception during movement in order to have collision-free navigation especially in crowded areas with numerous obstacles. Field of View (FOV) is one example of visual perception. FOV refers to the extent of the observable range seen by a human at any given moment where the human FOV is around 120 to 180 degrees (Shirish 2001). FOV is important since humans develop their perception of the environment during movement primarily from visual data.



Figure 5.20 The field of view that affects human movement

The importance of visual perception, especially the FOV, can be observed during the Move-Stop-Move behaviour where human movement becomes slower when looking for information during the journey. There is a possibility of performing the Move-Stop-Move behaviour in order to acquire persistent information so that a personal objective can be achieved. In general, older people and people with disabilities have a smaller FOV compared to young and able-bodied people due to reduction in physical ability and this is a contributory cause to the difficulty that older people and

people with disabilities have when moving within crowded spaces. Figure 5.20 shows the movement of the older people compared to other subjects. The image shows that physical ability limits the older peoples' movement especially when they need to look at the information located on the wall or higher areas.

Figure 5.21 shows an example of individuals in a group performing the Move-Stop-Move Behaviour using video frames. From the video analysis, the subjects were assumed to find a way to a specific area or direction. This can be observed by the way the subjects communicate with each other, pointing to some direction. During the movement, their FOV were directed to the information located on the floor in frame 2 (the man pointing at the information). After pointing at the information and confirming the information, the subjects were observed moving faster towards the information or direction.

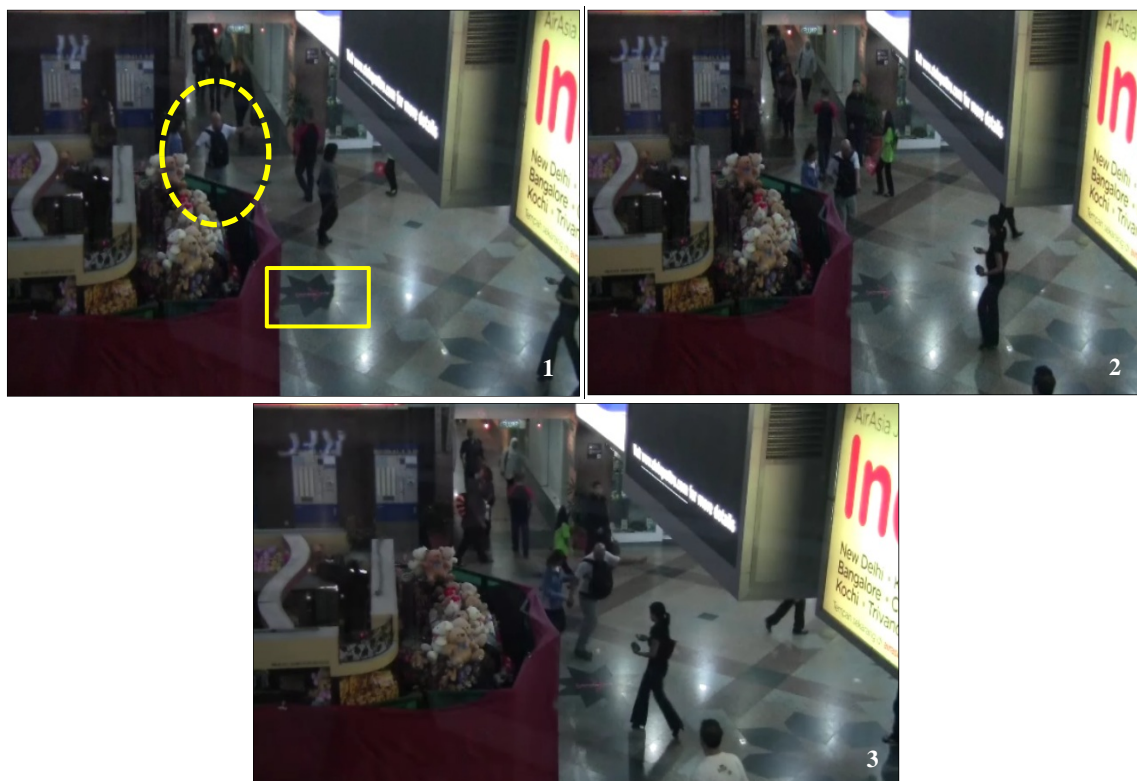


Figure 5.21 *The differences in field of view during the movement*

Figures 5.20 and 5.21 show that information located on a wall or on the floor become an important reference for people. It also shows that during the movement, visual perception plays an important role in human behaviour. Visual perception can also affect other humans in the crowd especially when subjects stopped in the middle of the crowd to look at the information. The situation can produce jamming situation within the crowd.

5.2.3 Speed of Movement

Speed of movement refers to the humans' walking speed and can be classified into slow, average, fast and extra fast. According to Syed Shazali (2010), a slow speed can be observed when humans have limited physical ability, such as older people walking with a cane. Average speed of movement can be observed when people are walking alone without obstruction or distraction on a level walking pathway. Jogging slowly or overtaking others from a tailgating state is an example of fast speed of movement and the extra fast speed of movement can be observed when people do a fast jog or run..

Based on the video observation, humans were observed to have slow or average speed of movement when performing the Moving Through or Move-Stop-Move behaviours. In Move-Stop-Move behaviour the speed of movement become slow or average because the humans needed more time to look around the area for information or activities such as buying a ticket. During the slow or average speed of movement humans were observed to be 'more relaxed' and 'rushing less'. Older people were also observed moving with the lower speed.

However, when performing the Competitive or Passing Through behaviour humans were observed to have faster (fast or extra fast) speed of movement. Figure 5.22 shows an example of an individual (marked with a yellow arrow) moving with fast or extra fast speed from frame 1 to

frame 4. The subject was also observed finding available spaces to move by avoiding and competing with other subjects. By using the video observation the humans that performed the fast or extra fast can be easily observed through the shorter time taken to move within the observation area.



Figure 5.22 *Different speed of movement from recorded video*

Based on video observation, the speed of movement also correlates with other factors such as personal objective and crowd density. People that have an urgent personal objective, for example catching for a train, will move more quickly. Other people such as a family including children tend to move more slowly. Research by Thompson et al. (1995) showed that human speed of movement becomes slower when the crowd density becomes higher. A detailed discussion on crowd density is given in Section 5.2.5.

5.2.4 Personal Space

Personal space refers to the invisible surrounding or territory around people. Personal space is considered as a social condition that affects communication or contact between humans. The personal space is divided into four categories known as the Intimate, Personal, Social Consultative and Public Zones based on the distance between humans within the public spaces. In general, older and disabled people have a larger personal space compared to the young and able-bodied (Syed Shazali 2010).

Based on video observation, most humans attempted to maintain their personal space during the movement and avoid colliding with others. Although the crowd density became higher where limited space was available people were not colliding with each other. This is an example where personal space affected human movement. Another example was the movement of family members within a crowd. The family members were observed to be moving very close together. Personal space can also be observed when people move around with luggage or other devices. Figure 5.23 shows an example where the workers moving with the green bin have greater personal space. Other people move apart to give a space for the worker.

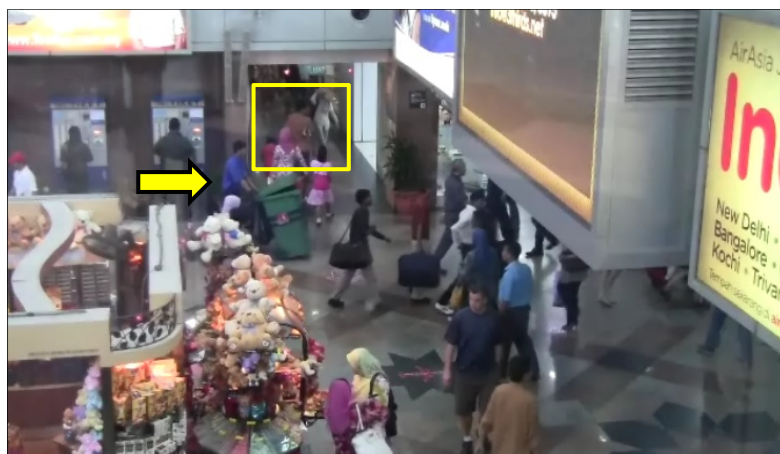


Figure 5.23 *The personal objective of the subjects*

5.2.5 Crowd Density

Since humans need space (personal space) to move from one area to another, it is notable that space plays an important role in human movement and behaviour. Based on the video observation conducted, crowd density was one of the other factors affecting human movement and behaviour. Crowd density refers to the number of people per square meter for a stationary or moving crowd. Human speed of movement is decreased when crowd density is increased and the scenario can be seen clearly in the recorded video especially during the peak time of the recording session.

Research by Thompson et al. (1995) and Fang et al. (2003) also confirms that the crowd density affects human movement. Humans will move at a lower speed when the crowd density becomes higher. An additional problem was that, individual human movement and behaviour was difficult to observe when crowd density increased since humans simultaneously performed different types of behaviour. During the video observation analysis, replays were more frequently required using the observation software to understand human movement and behaviour high density crowds. Figure 5.24 shows an example of moderate or high density crowd at the observation area.



Figure 5.24 *The moderate or high crowd density*

A high density crowd can create the bottleneck situation when people stop in the middle of the area. The bottleneck within the crowd produces the Queuing or Competitive behaviour within the humans. The situation was observed to affect the speed of movement. Crowd density also affects the avoidance angle and distance between humans. Humans also need to control the range (personal space) between others.

5.2.6 Avoidance Angle or Distance

Avoidance is an action performed by humans to keep away from colliding with other humans or obstacles. Based on the observations conducted, the avoidance angle or distance was a factor when people performed the Avoidance (avoid others in opposite direction) and Competitive (avoid others in same direction to overtake) behaviours. The avoidance angle or distance was observed to have a correlation with crowd density and visual perception.

In high density crowds humans were observed to have limited time to change their avoidance angle or distance. The avoidance angle was changed very quickly due to the closer distance between the humans. In some cases, humans only managed to twist their body to avoid collision with others. The same scenario was also observed by Rymill et al. (2005) and was known as 'step-and-slide'. In 'step-and-slide' human *was not total detour and avoidance of contact, but slight angling of the body, a turning of the shoulder and an almost imperceptible side step.*

On the other hand, in low density crowds humans were observed to have much time to avoid other humans or obstacles. The avoidance can be performed earlier as the humans see other humans on the movement path. Only a small angular direction change was needed in order to avoid others. Figure 5.25 shows an example of a change of avoidance angle or distance occurring in a low

density crowd. The worker (shown by a yellow arrow) only needs a small angular direction change to avoid other humans in the middle of the movement path without any need to stop the trolley.



Figure 5.25 *The avoiding angle or distance*

5.3 Summary

This chapter discussed the results from video observational studies conducted in Chapter 4. Nearly 19,000 individuals were observed within the six hours of video recording. The individuals were divided into six different behaviours including the Moving Through, Move-Stop-Move, Queuing, Competitive, Avoiding and Passing Through,.

There are several important points that can be concluded from the chapter;

1. Moving Through and Move-Stop-Move behaviour were derived from the conceptual behaviour of free direction movement. The majority of humans were observed moving with free direction movement with nearly 16,000 individuals performing the Moving Through behaviour. This result indicates that the observation area had sufficient space for humans to move around and maintain their own personal space.
2. The gap between individuals in a group and speed of movement were the major differences that were observed in Moving Through behaviour. Move-Stop-Move behaviour can affect the movement and behaviour of the whole crowd when humans stop in the middle of the movement path and develop a bottleneck situation.
3. Queuing and Competitive behaviour were derived from the conceptual behaviour of same direction movement. Queuing and Competitive behaviour were difficult to observe within the recorded video since the observation area was considered to be spacious enough to accommodate the movement. Queuing and Competitive behaviour were observed when the spaces become limited for humans to move such as in bottleneck areas.
4. Avoiding and Passing Through behaviour were derived from the conceptual behaviour of opposite direction movement. Humans have to perform an alternative route or consider a change to their avoidance angle or distance to avoid other humans in Avoiding behaviour.

Individual in a group and individuals that move with luggage, trolleys and other devices were observed to be more dominant and easily performed the Passing Through behaviour.

5. Personal Objective, Visual Perception, Speed of Movement, Personal Space, Crowd Density and Avoidance Angle or Distance were considered as the major factors affecting human movement and behaviour in crowded spaces.

The next chapter describes how the understanding gained from the analysis of the observational studies was used in the creation of a prototype human behaviour simulation system.

Chapter 6: Software Design and Modelling

This chapter discusses the use of DarkBASIC Professional gaming software as a tool to simulate human movement and behaviour in crowded areas. The discussion starts with the purpose of the software and software design methodology that maps the process to convert human movement and behaviour from the real world to the virtual environment. The six factors affecting human movement and behaviour in the real world were applied as the parameters for each entity in the virtual environment. Two types of simulation were conducted for this research focusing on the software validation and case studies. The simulation flowchart was developed as a step by step process to assist the understanding of the simulation.

6.1 Purpose of the Software

In this research, DarkBASIC Professional gaming software is selected to simulate the human movement and behaviour analysed from the real world. As a design tool, there are several purposes of the software as follows;

1. To study the flow of people in crowded areas including older people and those with disabilities
2. To improve the movement flow by including different barriers in modification of the facilities design
3. To observe different crowd scenarios including low and high density situations
4. To predict different situations that might occur within crowded areas including emergency situations

6.2 Software Design Methodology

The software design methodology discusses the important steps taken in order to simulate human movement and behaviour in the virtual environment using DarkBASIC Professional software. Three important discussions include the design of (i) model, (ii) parameters and (iii) entities. In the design of the model the discussion focuses on the steps taken to convert the human movement and behaviour from the real world to the virtual environment. The design of parameters refers to the source code that represents the six parameters in the virtual environment and the design of entities details the types of entities defined for the simulation.

6.2.1 Design of the Model

The design of the software is based on the human movement and behaviour in crowded areas taken from the video observation sessions conducted at the Stesen Sentral Kuala Lumpur, Malaysia. The steps taken for the software design are based on the enhancement of the video observational analysis method conducted in Chapters 4 and 5. In general, the video observational analysis method is summarised in Figure 6.1. The video observational analysis starts with the focus subject which is the individual human in crowded areas with three focus movements of free, same and opposite direction.



Figure 6.1 Video observational analysis method

The six different types of behaviour are derived from the focus movements, namely Moving Through, Move-Stop-Move, Queuing, Competitive, Avoiding and Passing Through behaviours. Based on the video observational analysis, six different factors are recognized affecting human movement and behaviour in crowded areas. The factors are Personal Objective, Visual Perception, Speed of Movement, Personal Space, Crowd Density and Avoidance Angle or Distance (a detailed discussion was provided in Chapters 4 and 5).

The steps taken in Figure 6.1 are enhanced and applied for the software design model as shown in Figure 6.2. In software design the focus subject for the virtual environment is the individual human in crowded areas, similar to the real world analysis subject. However, in the virtual environment the factors affecting human movement and behaviour are used as the parameters for each subject. After the parameters for each individual subject are established, different types of movement are designed. Similar to the real world analysis the free, same and opposite direction of movement are selected for the virtual environment.



Figure 6.2 *Software design model*

The movement of the entities in the virtual environment is analysed and compared with the movement in the real world in order to understand the similarities and differences. The advantages and limitations of the software are considered during the design process. Lastly, selected case studies are designed to evaluate the software. In this research, the selected case studies include the multi-mode transportation system (the Stesen Sentral, Kuala Lumpur), bottleneck and non-bottleneck layout of a building.

6.2.2 Design of Parameters

As described earlier in Section 6.2.1, the factors affecting human movement and behaviour in the real world are considered as the parameters for each entity in the virtual environment. The parameters play important roles in developing different types of simulation that utilise different movement scenarios in the real world. However, some modification has been made in order to represent the parameters in the virtual environment. Table 6.1 describes the representation of the parameters from the real world in the virtual environment. The representation in the virtual environment is the command or programming source code applied for each entity.

Table 6.1 Individual parameters in virtual environment

No.	Parameters	Representation in Virtual Environment
1.	Personal Objective	<i>Position Object</i> <i>AI Entity Go to Position</i>
2.	Visual Perception	<i>AI Set Entity View Arc</i> <i>AI Set Entity View Range</i>
3.	Speed of Movement	<i>AI Set Entity Speed</i>
4.	Personal Space	<i>AI Set Radius</i>
5.	Crowd Density	Based on number of humans over floor size
6.	Avoidance Angle or Distance	Based on DarkAI from the software

a. Personal Objective

The Personal Objective in the virtual environment is represented by the commands *Position Object* and *AI Entity Go to Position*. The *Position Object* command defines the initial position for each entity in the virtual environment before the entities perform any movement. The entities move towards the selected location using the *AI Entity Go to Position* command. The Personal Objective parameter in the virtual environment is shown as the red path in Figure 6.3. In this research, the Personal Objective parameters (the *Position Object* and *AI Entity Go to Position* command) are applied to develop the selected movements, namely the free, same and opposite directions. A detailed discussion on the selected movement is conducted in Section 6.2.

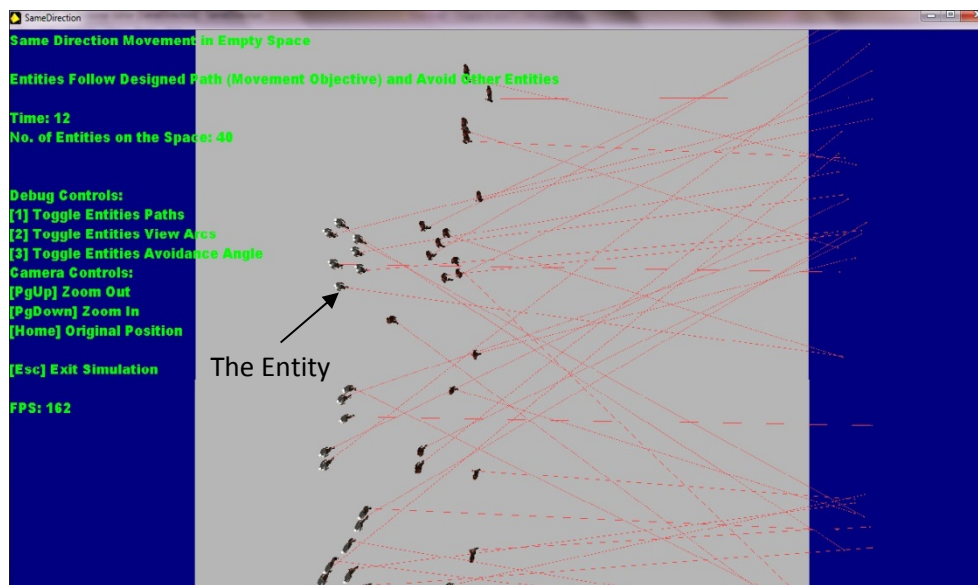


Figure 6.3 Personal Objective parameter in the virtual environment

b. Visual Perception

The Visual Perception parameter in the virtual environment is represented by the view arc and the view range as shown in Figure 6.4. The view arc is the angle at which the entities can see their surroundings. In DarkBASIC the value of the view arc is in the range 1 to 360 degrees and is defined by the *AI Set Entity View Arc* command. The view range is the distance the entities can see from the current location and is defined by the *AI Set Entity View Range* command. The entities in the virtual environment are able to see anything that appears within the view range and the view angle. Figure 6.5 shows a representation of the Visual Perception parameter (the arcs) alongside the Personal Space parameter (the circles).

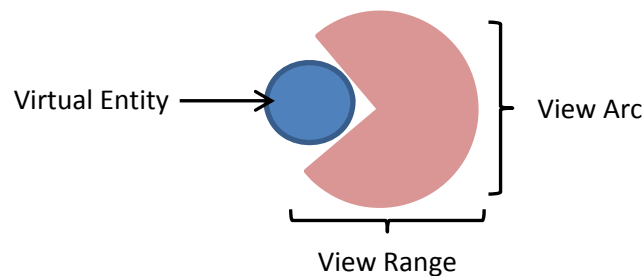


Figure 6.4 View Arc and View Range in Visual Perception for virtual entity

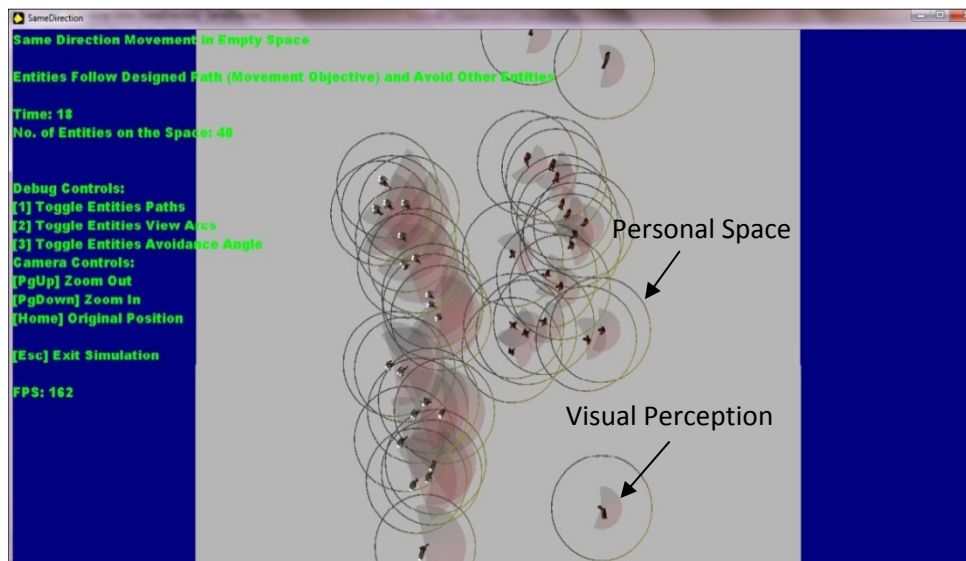


Figure 6.5 Personal Space and Visual Perception parameter in the virtual environment

c. Speed of Movement

The Speed of Movement in the virtual environment is represented by the command *AI Set Entity Speed*. The command sets the movement speed of the entity in DarkBASIC units per second (unit pixels). A detailed discussion on the selected speed of movement for the entities is presented in Section 6.1.4 (Design of Entity).

d. Personal Space

The Personal Space in the virtual environment is represented by the *AI Set Radius* command. The command sets the global radius that is used by all entities in the virtual environment. The command controls how much space is allowed between obstacles and the waypoints that define movement around the entities. Since the entities use the waypoints to navigate around the virtual environment, the entities will attempt to maintain at least the *AI Set Radius* distance from all obstacles. The Personal Space parameter was illustrated previously in Figure 6.5.

e. Crowd Density

Crowd density refers to the total number of entities within the floor area. In this research, the floor area for the simulation is designed recognising that the maximum number of entities in order to ensure a viable simulation is limited to 90. The crowd density is designed with three scales namely low, medium and high crowd as shown in Table 6.2. Although in the simulation conducted the number of entities required can be selected manually by the user, Table 6.2 below is applied as the guideline for the analysis conducted later in Chapter 7.

Table 6.2 *Type of crowd and definition for the research*

No.	Type of Crowd	Definition of the Crowd
1.	Low Density	The movement of 30 entities within 600 unit pixels × 600 unit pixels (30 m × 30 m) area
2.	Medium Density	The movement of 60 entities within 600 unit pixels × 600 unit pixels (30 m × 30 m) area
3.	High Density	The movement of 90 entities within 600 unit pixels × 600 unit pixels (30 m × 30 m) area

f. Avoidance Angle or Distance

Avoidance Angle or Distance refers to the situation where the entities in the virtual environment avoid each other during the movement. In this research, the Avoidance Angle or Distance is based on the DarkAI effect from the movement as shown in Figure 6.6. The Avoidance Angle or Distance is represented by the green areas in the figure. The Avoidance Angle or Distance is also affected by other parameters such as Visual Perception and Personal Space. When the floor area becomes more crowded (number of entities increased), the avoidance behaviour is observed to occur many times.



Figure 6.6 *Avoidance Angle or Distance parameter in the virtual environment*

6.2.3 Controllable and Uncontrollable Parameters

The parameters for individual entities in the virtual environment can be divided into two categories known as controllable and uncontrollable as shown in Figure 6.7. The controllable parameters refer to the adjustable conditions of the parameters where the values of each parameter are defined in the source code before the program is executed. The values can be based on the literature survey or assumptions made by the programmer.

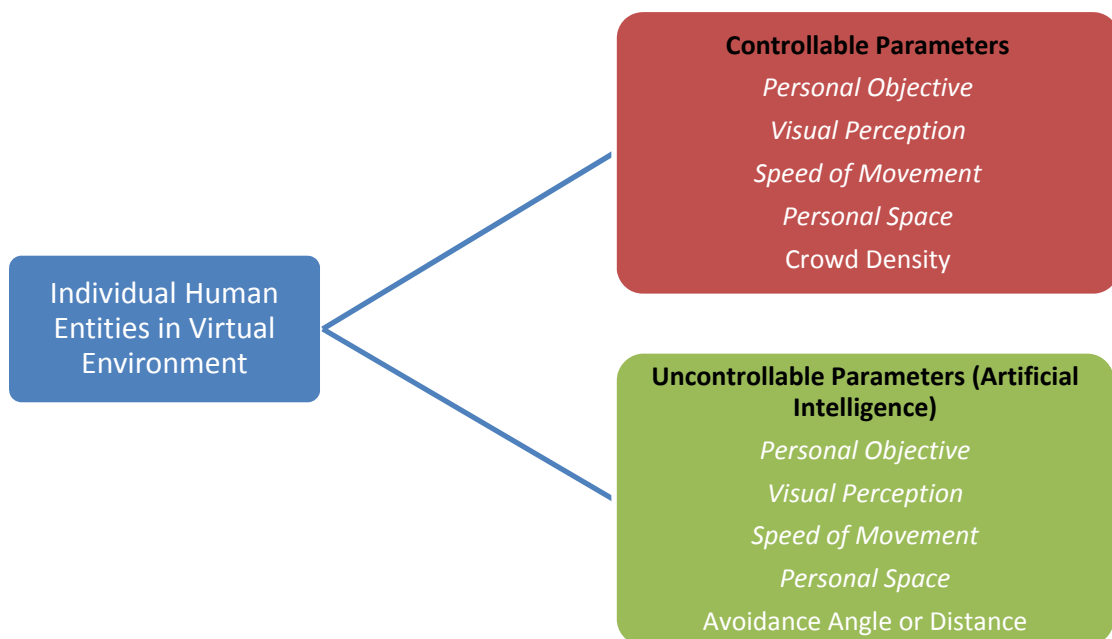


Figure 6.7 *Controllable and uncontrollable parameters in software design*

For example, the speed of movement for adult entities is fixed at 1.2 m/s based on the literature survey whilst the view range for older entities is assumed to be 2 m for normal or initial conditions. In this case, the speed of movement and view range (Visual Perception) will be written in the source code of the program using DarkBASIC units. However, how the speed of movement is changed or becomes slower due to obstacle avoidance during the movement or changes of view range due to crowd density cannot be controlled by the programmer. Such elements are decided by the artificial intelligence command related to the speed of movement. Therefore, the uncontrollable

parameters refer to conditions where the decision or movement related to the parameters are affected by the artificial intelligence in the software package after the program is executed.

In this research the Personal Objective, Visual Perception, Speed of Movement and Personal Space are considered as the controllable and uncontrollable parameters. The Crowd Density is the only parameter that is considered to be controllable since the user can select the required number of entities to move on the fixed size of floor area. On the other hand, the Avoidance Angle or Distance is the only parameter that is considered as being uncontrollable. The avoidance angle or distance is based on the artificial intelligence command of the software package and is also affected by the value of Personal Space and Visual Perception (view arc and view angle) parameters.

6.2.4 Design of Entities

In the software design two subjects, an adult and an older people (known as older entity or older subject in the simulation) are selected as the entities for virtual environment simulation. Both entities are designed with the three dimensional (3D) design based on the work of Wai Loon (2011) to provide more realism for the simulation. Figures 6.8 and 6.9 shows the design of the entities.

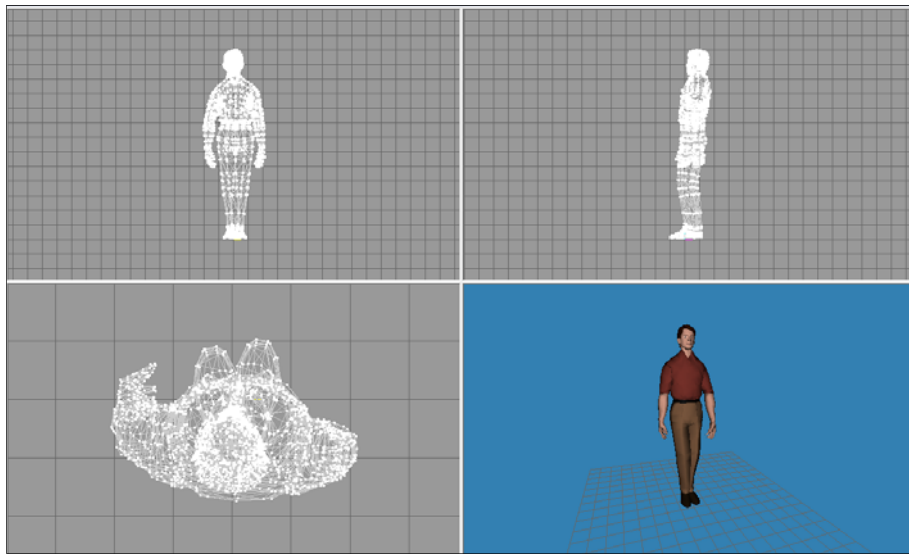


Figure 6.8 *Adult entity in 3D design* (Wai Loon 2011)

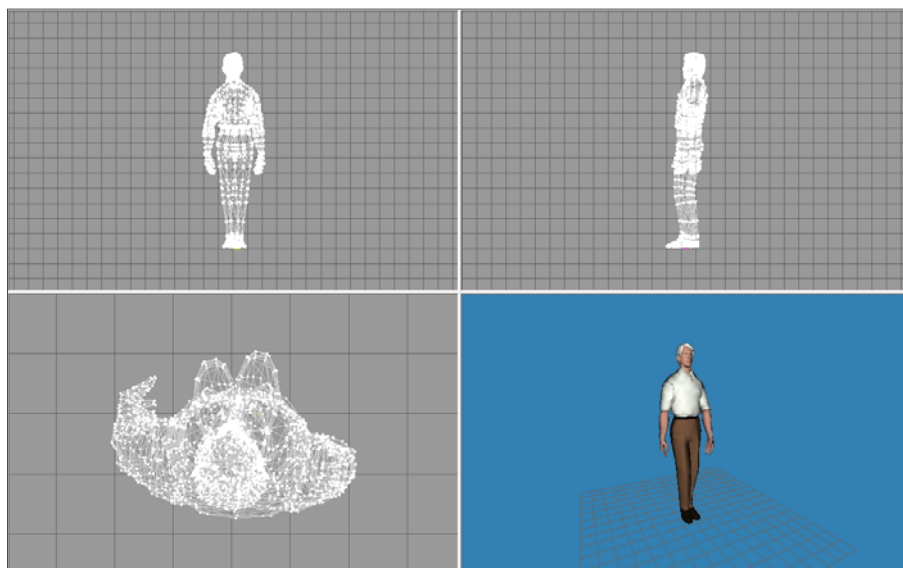


Figure 6.9 *Older entity in 3D design* (Wai Loon 2011)

An experiment in the virtual environment was conducted previously by Wai Loon (2011) using the entities to measure the size of DarkBASIC units for real world measurements. The conversion unit is important to ensure the movement of entities or any design in the virtual environment provides a similar result in the real world. The unit pixels per second are used later in the programming source code (refer to Appendix B). The experimental result shows that the 1 unit pixel (DarkBASIC unit) is equal to 5 cm in the real world. Table 6.3 shows the source code for adult and older entities in the virtual environment. The values of the parameters were based on Shirish (2001), Teknomo (2002) and assumptions from the author.

Table 6.3 *Adult and Older entity source codes in the virtual environment*

Adult Entity	Older Entity
<i>AI Set Entity Speed I, 24</i>	<i>AI Set Entity Speed I, 16</i>
<i>AI Set Entity View Arc I, 160, 210</i>	<i>AI Set Entity View Arc I, 140, 190</i>
<i>AI Set Entity View Range I, 40</i>	<i>AI Set Entity View Range I, 20</i>
<i>Color Object I, RGB (0, 0,255)</i>	<i>Color Object I, RGB (255, 0, 0)</i>

The adult entity is set to be 24 unit pixels per second or 1.2 m/s speed of movement. The view arc is set between 160 to 210 degrees with view range of 40 unit pixels or 2 m. The adult entity is also designed with the blue colour based on the DarkBASIC RGB (Red, Green and Blue) colour spectrum. On the other hand, the older entity is set to have 16 unit pixels per second or 0.8 m/s speed of movement. The view arc is set between 140 to 190 degrees with the view range of 20 unit pixels or 1 m. Lastly, the older entity is designed with red colour based on the DarkBASIC RGB colour spectrum

6.3 Types of Simulation Conducted in Virtual Environment

Two types of simulation were conducted in the virtual environment focusing on the software validation and case studies as shown in Figure 6.10. The software validation includes the simulation of the entities movements in free, same and opposite directions. The case studies include the simulation of a multi-mode transportation system, bottleneck and non-bottleneck layouts. Each simulation is developed in a modular pattern and each can be executed independently. The simulations are carried out as part of the analysis of the program and will be discussed further in Chapter 7. In this section, general discussion on the simulations and simulation flowchart is presented.

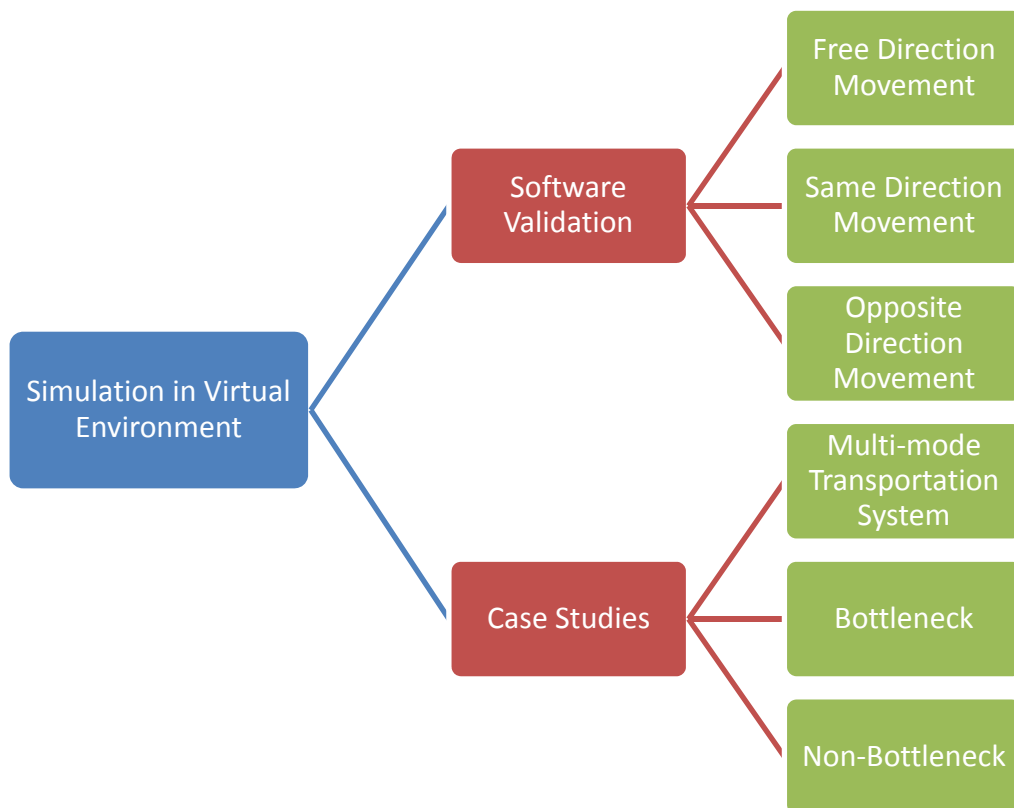


Figure 6.10 Overview of simulation conducted in virtual environment

6.3.1 Free Direction Movement

The free direction movement simulation is conducted to observe the movement of entities along the movement objective (personal objective parameter) and to understand the basis of programming. The simulation starts with the setup of the parameters and total number of entities required in the source code. In this simulation the total number of entities is set to be 90 entities. Instead of using the *Position Object* and *AI Entity Go to Position* command to represent the personal objective parameter, the free direction movement used the *AI Make Path*, *AI Path Add Point*, *Position Object* and *AI Entity Assign Patrol Path* command. The free direction movement source codes are as follows;

AI Make Path 1

AI Path Add Point 1, 200, -200

AI Path Add Point 1, -200, 200

AI Path Add Point 1, 200, 200

AI Make Path 2

AI Path Add Point 2, -275, 275

AI Path Add Point 2, 275, -275

AI Path Add Point 2, -275, -275

AI Path Add Point 2, 275, 275

AI Make Path 3

AI Path Add Point 3, -150, 150

AI Path Add Point 3, 150, -150

AI Path Add Point 3, -150, -150

AI Path Add Point 3, 150, 150

Position Object I, RND (600) - 300, 0, - (RND (40) + 325)

AI Entity Assign Patrol Path I, RND (2) + 1

The source code shows that there are three movement objectives developed for free direction movement (*AI Make Path* command). Each movement objective is identified using the *AI Path Add Point* command. The *AI Path Add Point* command contains different points that identify the movement area of the entities. After the number of the movement objective and the area for each movement is defined, the entities in the virtual environment are located at the start point (shown in Figure 6.11) using the *Position Object* command. At the same time the *AI Entity Assign Patrol Path* command is applied with the random function (RND) to randomly select the movement objectives for the entities. After the program is executed, the entities are created at the start point and moved around the floor area. The simulation will be terminated when the close window is clicked. The movement of the entities will be observed although there is no specific output collected from the movement.

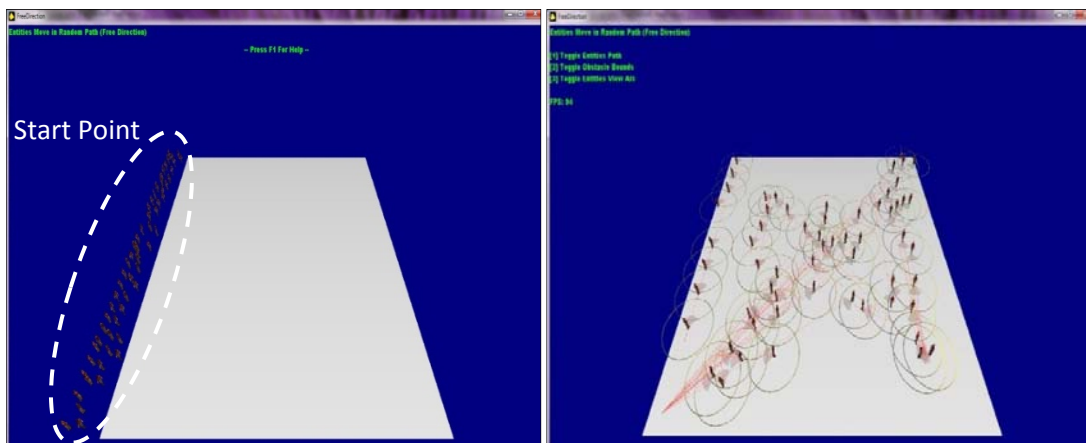


Figure 6.11 *Free direction movement in the virtual environment*

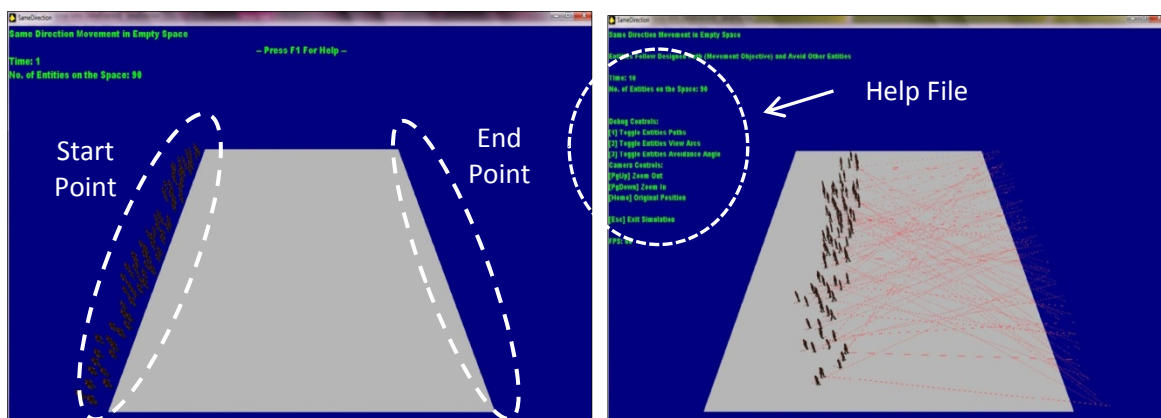
6.3.2 Same Direction Movement

Same direction movement simulation is conducted to understand the movement of entities in one direction. The same direction movement source codes are as follows;

Position Object I, RND (600) - 300, 0, - (RND (40) + 325)

AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)

The *Position Object* command is used as the start point of the entities in the virtual environment. As shown in Figure 6.12(a), the value of *RND (600) - 300, 0, - (RND (40) + 325)* in the *Position Object* command represents the initial or start point area for the entities. The entities are designed to move in one direction using the command *AI Entity Go to Position*. The value of *(RND (600) - 300), (RND (40) + 325)* in the *AI Entity Go to Position* command represents the movement objective or end point for the entities. The same direction movement simulation flowchart is shown in Figure 6.13. The simulation starts with the setup of the parameters in the source code. After the program is executed, the welcome screen will appear. The welcome screen consists of the description and the instructions for the program.



(a)

(b)

Figure 6.12 Same direction movement in the virtual environment

In this program, the user is required to input the total number of entities for the simulation. The user is only allowed to input a number between 1 and 90 (to represent the number of entities required for the simulation) or else a warning will appear and the program will not be executed. After the total number of entities is decided, the user is required to specify the number of adult entities for the simulation. The program will then calculate the number of older entities based on the differences between total number of entities and total number of adult entities. Lastly, the user is required to input the running time for the simulation in seconds.

After the total number and distribution of entities with a running time have been determined, the entities are created at the start point. The start point is the area where the entities are created before the movement is performed. In the same direction movement simulation only one start point is created. Once the total number of entities is created, the entities will move towards the end point. The end point is considered as the movement objective of the entities. The movement will be continued as a loop and when an entity reaches the end point it will be deleted and recreated at the start point. The time taken for each entity to complete the movement from start to end point is recorded in a data file. The simulation will be terminated after reaching the total running time.

Besides showing the start and end points, the simulation screen also displays related information of the simulation. Figure 6.12(b) shows the basic display of the simulation that contains the description of the simulation, the running time and the total number of entities within the simulation. The display also includes F1 button for the help file. When the F1 button is pressed, the user is able to acquire more information related to the simulation as shown in Figure 6.12(b). For example, the user is able to observe the effect of the parameters on the movement of entities and to observe the movement from a different angle of view. The detailed source code for the same direction movement simulation is summarised in Appendix B.

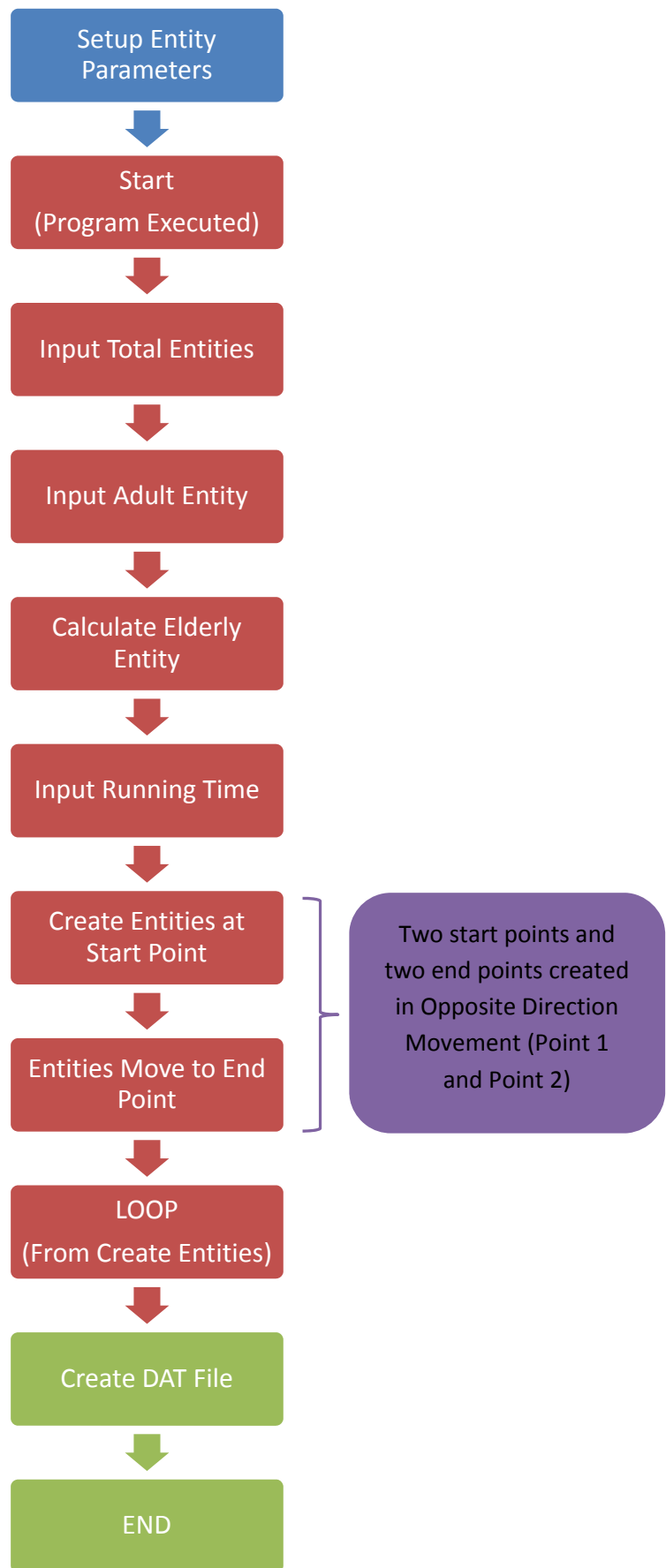


Figure 6.13 Same and Opposite direction movement simulation flowcharts

6.3.3 Opposite Direction Movement

Opposite direction movement simulation is conducted to understand the movement of entities in two different, opposing, directions. The opposite direction movement is developed based on the enhancement of the same direction movement command. The command enhancement can be seen in simulation flowcharts in Figure 6.13 where there are two start and end points created for the entities. The opposite direction movement source codes are as follows;

Position Object I, RND (600) - 300, 0, (RND (40) + 325)

AI Entity Go to Position I, (RND (600) - 300), - (RND (40) + 325)

Position Object I, RND (600) - 300, 0, - (RND (40) + 325)

AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)

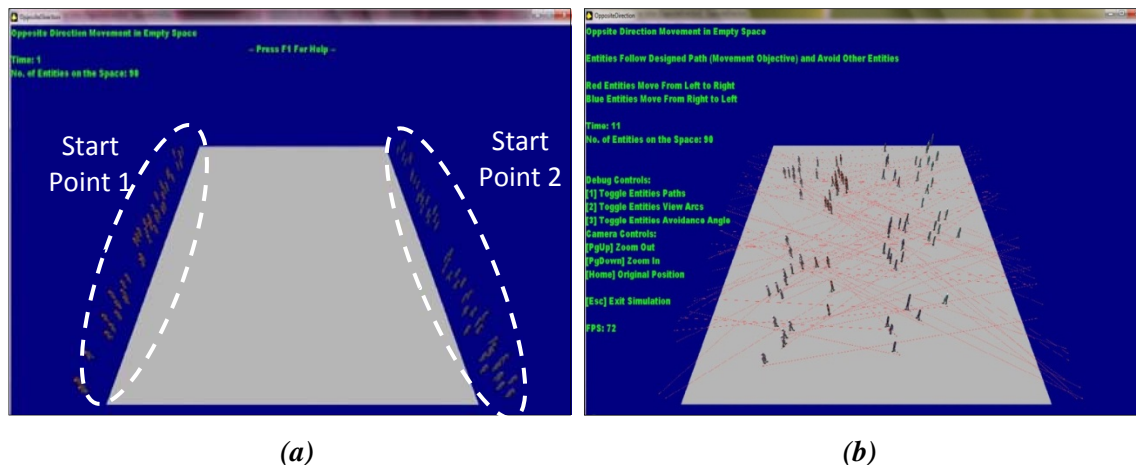


Figure 6.14 Opposite direction movement in the virtual environment

In opposite direction movement, there are two initial positions designed for the entities using the *Position Object* command. As shown in Figure 6.14(a), the initial position is considered either as Start Point 1 or Start Point 2. The two positions are opposite to each other as shown in bold in the source code. Start Point 2 becomes the end point for the entities at Start Point 1 while Start Point 1 becomes the end point for the entities at Start Point 2. The distribution of entities to Point 1

or Point 2 is decided by an artificial intelligence command. In opposite direction movement, more avoidance behaviour occurs between the entities as shown in Figure 6.14(b). The detailed source code for opposite direction movement simulation is summarised in Appendix B.

6.3.4 Multi-mode Transportation System

The multi-mode transportation system simulation as shown in Figure 6.15(a) is conducted to simulate the observation area which is the Stesen Sentral, Kuala Lumpur (Figure 6.15(b)). The simulation is conducted to evaluate the effect of different designs and obstacles to human movement in a crowd. The movement of the entities in the multi-mode transportation system applied the similar concept with opposite direction movement where the entities move from two start points.

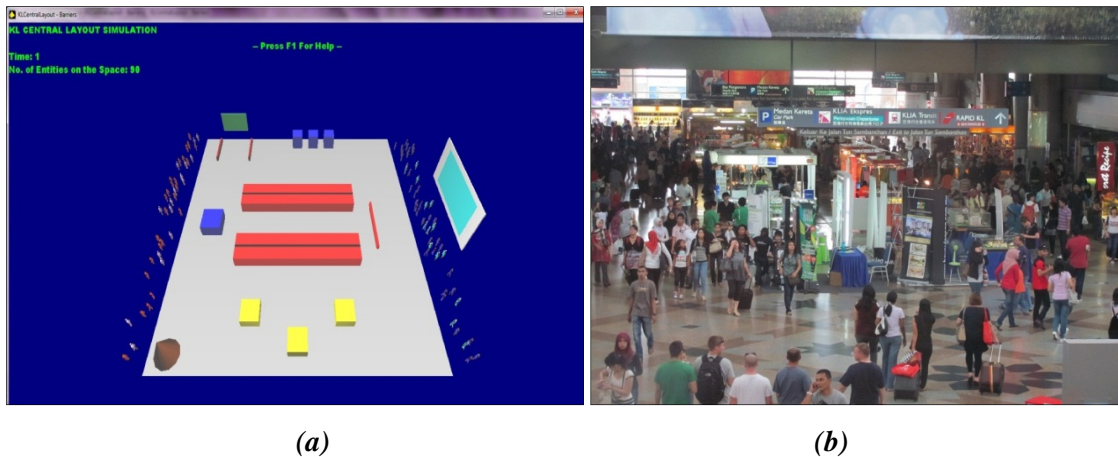


Figure 6.15 The Stesen Sentral simulation in the virtual environment

6.3.5 Bottleneck and Non-bottleneck Layout Simulation

Bottleneck and Non-bottleneck layout simulation (Figure 6.16) is conducted to understand the effect of bottleneck and non-bottleneck layouts on human movement in a crowd. Although the

Bottleneck and Non-bottleneck simulations are conducted separately for this research, both simulations have a similar development concept. Therefore, both simulations will be explained together in this section. The simulation flowchart for Bottleneck and Non-bottleneck simulation is shown in Figure 6.17.

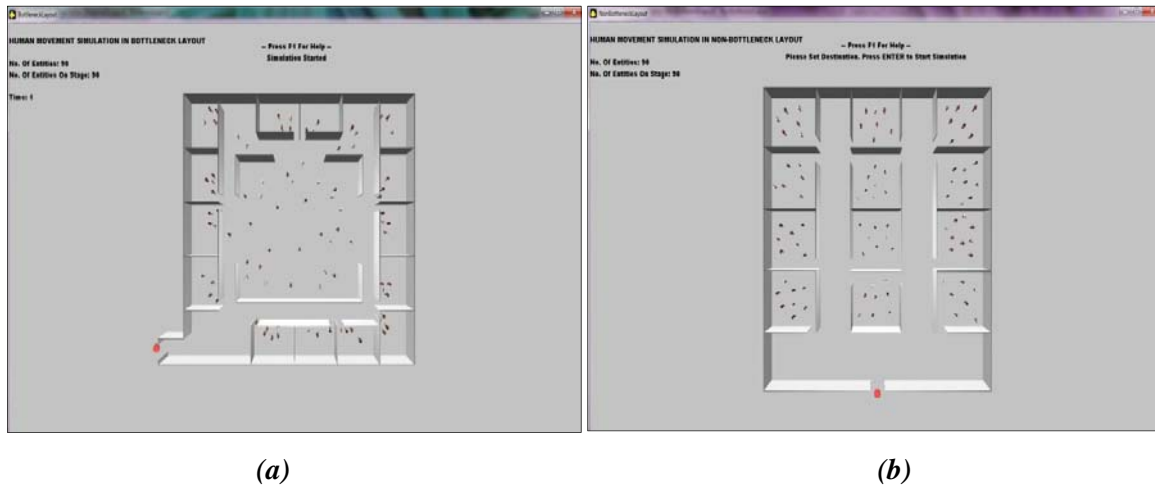


Figure 6.16 Bottleneck and Non-bottleneck layout in virtual environment

The simulation starts with setting up the entity parameters in the source code. After that, the program is executed and the user selects the number of adult and older people required for the simulation up to a maximum of 90 entities per simulation. The user has to select the entity number and the location of the entity manually where the adult entity can be created by using the mouse right click while the older entity is created when the left mouse is clicked.

When the user is satisfied with the number of entities required for the area, the *SPACEBAR* button is depressed. The user then sets the destination of the entities. For this simulation, the exit door will be set to be the final destination of the entities. The simulation will be started if the *ENTER* button is pressed and the entities will move towards the selected destination. The detailed source code for multi-mode transportation system, bottleneck and non-bottleneck simulation is summarised in Appendix B.

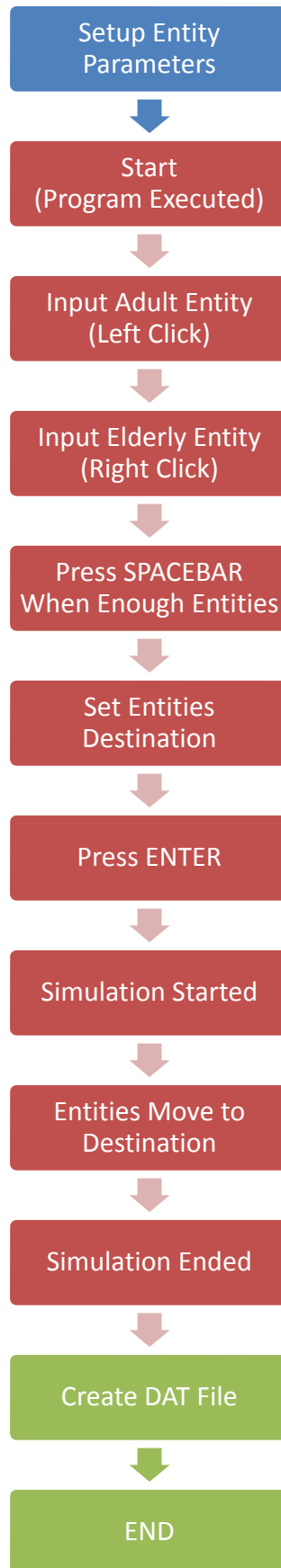


Figure 6.17 Bottleneck and Non-bottleneck layout simulation flowcharts

6.4 Summary

The process to convert the understanding of human movement and behaviour from the real world to the virtual environment needs a thorough consideration to ensure there is similarity between the two. In this research, the software design and modelling was developed based on the enhancement of the video observational analysis method. The fundamental idea was to apply the six factors affecting human movement and behaviour in the real world as the parameters for the simulation using DarkBASIC Professional software. Two types of subjects; the adult and older people were selected as the entities in the virtual environment to reflect on the philosophy of ‘design for all’. Two types of simulation were conducted for this research to understand the source code, to cover different types of movement and design and to contribute new understanding towards human movement and behaviour using the simulation. In the next chapter, a detailed discussion on the software validation and case studies is provided.

Chapter 7: Software Validation and Case Studies

The previous chapter discussed the process involved in establishing the basis of the simulation of human movement and behaviour observed at the multi-mode transportation system. This chapter discusses the simulation results and analysis. Different parameter values that represent different real world scenarios are used to evaluate the simulation. Different types of simulation are designed to validate the software design. The simulation provides better insight towards the movement of entities in the virtual environment and can be used to predict human movement in the real world.

7.1 Introduction

The simulation conducted in this research is divided into two types; the software validation and case studies. The simulations are developed in order to understand human movement in the real world and to predict the effect of different facilities design on humans using the virtual environment. There are several steps involved in performing the simulation as shown in Figure 7.1. Setup refers to the process of selecting the parameter values that applied for each simulation. Different parameter values are selected for the virtual environment simulation to represent different movement scenarios in the real world.

Execution refers to the process involved after the program is started; for example the command to input the number of entities required for the simulation and other relevant information. Execution also refers to the effect of the artificial intelligence that is applied in the program. Output refers to the 'raw data' acquired after the program is terminated. In this research, the 'raw data' is the time taken for each entity to complete the movement. The 'raw data' is transferred manually to

the simulation database to acquire the simulation results. Figure 7.2 shows an example of the database developed for each simulation conducted. The simulation result is analysed through the graph. A detailed discussion is given in the next section.

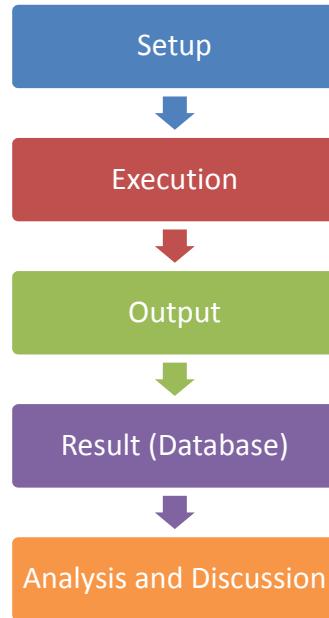


Figure 7.1 The simulation and analysis process

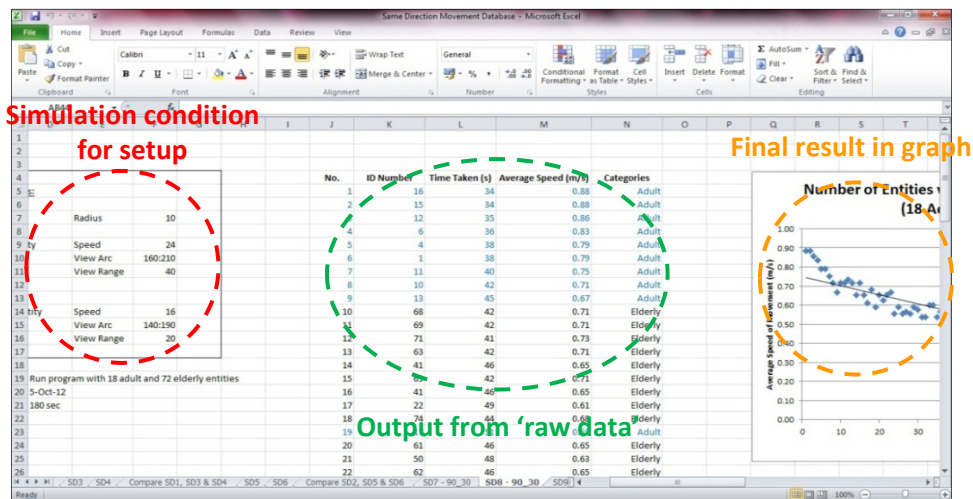


Figure 7.2 Example of database for the simulation conducted

7.2 Parameter Values for Simulation

Different parameter values are selected for the simulation to represent different scenarios of human movement in the real world. As shown in Table 7.1 there are five scenarios selected for the simulation. The simulation is started with the normal situation scenario that represents the initial condition for the simulation.

In the normal situation scenario, the adult entity is designed to move with a view arc of 160 to 210 degrees and 2 m view range. The speed of movement is set to be 1.2 m/s. At the same time, the older entity is set with a view arc of 140 to 190 degrees and 1 m view range. The speed of movement is set to be 0.8 m/s. The difference between the software validation and case studies simulation is the selected value of personal space parameter. In software validation, the adult and older entity personal space is determined as 0.5 m while in case studies, the personal space for adult and older entity is set to be 0.25 m.

Besides the normal situation scenario, the same and opposite direction movement is simulated using another three different scenarios. The first scenario is considered as the situation where the entities change their visual perception during the movement. The change in visual perception is an important phenomenon as humans in the real world change their visual perception on many occasions during movement such as in Move-Stop-Move behaviour. The visual perception condition is changed by setting a narrower view arc and a wider view range compared to the initial condition.

On changing the visual perception condition, the adult entity is set to have a view arc of between 140 and 190 degrees and a view range of 3 m whilst the adult entity is set with 120 to 170 degrees of view arc and 1.5 m of view range. The speed of movement and personal space for both entities is similar to the initial conditions. The speed of movement for the adult entity is set to 1.2

m/s whilst the older entity is set to 0.8 m/s. The personal space value is 0.5 m for both entities. The second scenario is conducted with the objective of observing the changes of personal spaces in the entities. In changes of personal space, the personal space for adult and older entity is set to be 0.25 m. The value of visual perception and speed of movement for both entities is similar to the initial conditions.

Table 7.1 Selected parameter values for simulation

No.	Scenario	Entity	Parameter	Value(s)
1.	Normal Situation for Software Validation – Free, Same and Opposite Direction Movement Simulation	Adult	Visual Perception	View Arc = 160:210 (degrees) View Range = 2 m
			Speed of Movement	1.2 m/s
			Personal Space	0.5 m
		Older People	Visual Perception	View Arc = 140:190 (degrees) View Range = 1 m
			Speed of Movement	0.8 m/s
			Personal Space	0.5 m
2.	Normal Situation for Case Studies – Multi-mode Transportation System, Bottleneck and Non-bottleneck Layout Simulation	Adult	Visual Perception	View Arc = 160:210 (degrees) View Range = 2 m
			Speed of Movement	1.2 m/s
			Personal Space	0.25 m
		Older People	Visual Perception	View Arc = 140:190 (degrees) View Range = 1 m
			Speed of Movement	0.8 m/s
			Personal Space	0.25 m
3.	Changes in Visual Perception (<i>Same and Opposite Direction Movement Simulation</i>)	Adult	Visual Perception	View Arc = 140:190 (degrees) View Range = 3 m
			Speed of Movement	1.2 m/s
			Personal Space	0.5 m
		Older People	Visual Perception	View Arc = 120:170 (degrees) View Range = 1.5 m
			Speed of Movement	0.8 m/s
			Personal Space	0.5 m
4.	Changes in Personal Space (<i>Same and Opposite Direction Movement Simulation</i>)	Adult	Visual Perception	View Arc = 160:210 (degrees) View Range = 2 m
			Speed of Movement	1.2 m/s
			Personal Space	0.25 m
		Older People	Visual Perception	View Arc = 140:190 (degrees) View Range = 1 m
			Speed of Movement	0.8 m/s
			Personal Space	0.25 m
5.	Emergency Situation (<i>Same and Opposite Direction Movement Simulation</i>)	Adult	Visual Perception	View Arc = 70:90 (degrees) View Range = 1 m
			Speed of Movement	2.4 m/s
			Personal Space	0.25 m
		Older People	Visual Perception	View Arc = 80:100 (degrees) View Range = 0.5 m
			Speed of Movement	1.6 m/s
			Personal Space	0.25 m

Finally, the third scenario is conducted to understand emergency situations through simulation in the virtual environment. In the simulation, the entities are assumed to move faster with a close focus on visual perception. However, at the same time the visual perception is assumed to be blocked by the faster movement of the all entities. The adult entity is set with 70 to 90 degrees of view arc with 1 m of view range. The speed of movement is set to be 2.4 m/s and the personal space is 0.25 m. The older entity is set with 80 to 100 degree of view arc and 0.5 m of view range. The speed of movement is set to be 1.6 m/s with 0.25 m of personal space.

7.3 Software Validation

Software validation is conducted to validate the lower levels of simulation to confirm that the modelling of the individual movements and behaviours in the virtual environment have some kind of agreement with the real world. It is a platform to examine the selection and usage of DBPro commands and the effects of DarkAI on the simulation.

The software validation provides information on the advantages and limitations of the simulations compared to the real world. It includes an understanding of the similarities and differences of the virtual entity movement based on the selection of different parameters compared to humans in the real world. Since this research work attempts to apply all factors affecting human movement and behaviour in the real world as the parameters for the virtual entities, software validation is an important process to ensure the objective can be achieved. This to ensure the simulation can be applied for other applications or case studies.

However, the software validation is limited to only three types of movement; free, same and opposite direction. The movements are focused only on one movement objective (one start point

and one end point) for each entity without any stopping point. This means that the simulation at the moment does not consider the Move-Stop-Move behaviour.

7.3.1 Free Direction Movement Simulation

The free direction movement simulation is conducted to observe the movement of entities within the movement objective (personal objective parameter) in the virtual environment. The simulation is also conducted to understand the basis of programming and the role of artificial intelligence commands (DarkAI) within the DarkBASIC Professional software. Although there is no specific output acquired from the simulations, observation of the simulations provided insight into the software and the source code commands.

a. Discussion on Visual Perception and Personal Space Parameters

An overview of the free direction movement simulation is shown in Figure 7.3. In the virtual environment, the entities (under the control of DarkAI) are observed attempting to maintain the values of visual perception and personal space declared earlier during the setup process. The simulation shows that the visual perception and personal space parameters play a significant role in the movement of entities in the virtual environment. Figure 7.3 shows that the entities are observed nearly trapped together during the movement especially when the majority of the entities move into the same area at the same time.

The effect of visual perception and personal space in the virtual environment is considered to be slightly different from human movement in the real world. In the real world, humans are observed to be able to adaptively control their visual perception and personal space. For example,

at peak times when the crowd density is higher humans adopt a smaller personal space and lower visual perception and continue to move around without colliding with others. On the other hand, during off-peak times where the crowd density is lower, humans are able to move around with larger personal space and higher visual perception.

The free direction movement simulation conducted indicated that the value of the visual perception and personal space parameters affect the movement of entities in the virtual environment. The two parameter values determine the avoidance angle/distance of the entities that are controlled by an artificial intelligence command in DarkAI. Although the parameters have a slightly different function in real world, the parameters are considered to provide a significant contribution towards simulation of the virtual environment.

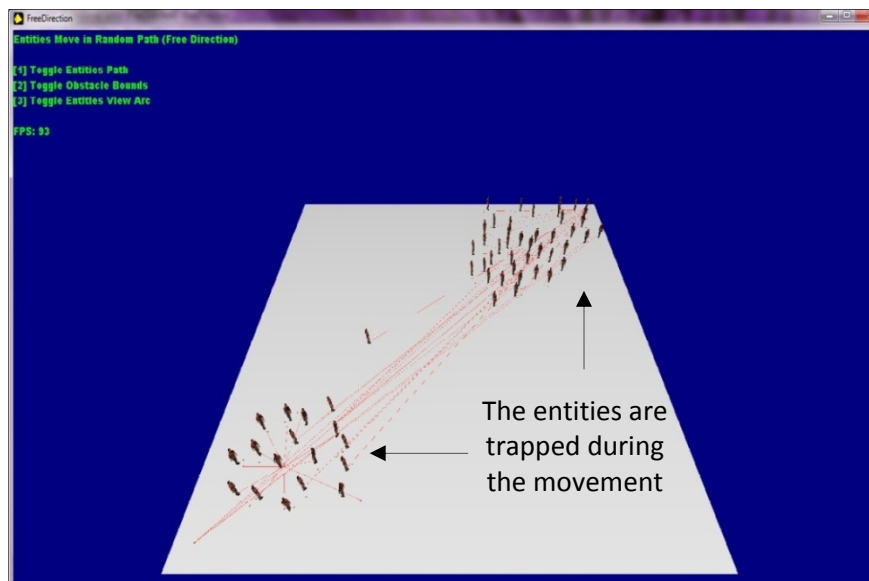


Figure 7.3 *The movement of entities in free direction movement*

b. Discussion on Personal Objective Parameter Representation

In the simulation of free direction movement four major commands (as discussed in Section 6.3); *AI Make Path*, *AI Path Add Point*, *Position Object* and *AI Entity Assign Patrol Path* are

applied to design the personal objective parameter in the virtual environment. The advantage of the command is that the movement of entities can be determined by the programmer. However, the movements created using the commands can cause the entities to be easily trapped during the movement as shown in Figure 7.3. Therefore, the command applied for the personal objective parameter is reconsidered for other movements.

7.3.2 Same and Opposite Direction Movement Simulation

Same and opposite direction movement simulation is conducted to simulate the movement of entities in same (one way) and opposite (two way) directions similar to human movement in the real world observed during the observational study. In this simulation, linear regression graphs are applied focusing on the entity arrival sequence and the average speed of movement. All entities start at the same time, and the entity arrival sequence refers to the order in which the entities eventually arrive at their destinations. The number of entities in the simulation will be 30, 60 or 90 for low, medium or high density crowds respectively.

The average speed of movement refers to the average speed that each entity has during the movement from their starting point to their ending point (movement objective). In the simulation, all entities are generated in the same start point area and move towards the same end point area. However, there are different factors that can affect the movement of entities towards the end point area. Using the linear regression graph, the movement pattern of the entities are observed and compared with the real world situation. Five important discussions arise from the simulation results including; the comparison between same and opposite direction movement, the crowd density, the changes of personal space and visual perception, the proportion of older entities and emergency situations.

a. Discussion on Comparison between Same and Opposite Direction Movement Simulation

The same and opposite direction movement simulations were conducted using 90 adult entities (high density crowd) and the results for both simulations are compared in Figure 7.4. Table 7.2 shows the average speeds for same and opposite direction respectively. The results show that the average speeds of entities in same direction movement is higher compared to the opposite direction movement. Based on observations conducted using the simulation, the entities moving in opposite direction movement need to avoid other entities and therefore, the movement becomes slower and more time is needed in order to reach the movement objective.

Table 7.2 *Average speeds for same and opposite direction movement*

Types of Movement	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)
Same direction	1.00	0.47
Opposite direction	0.83	0.41

The simulation results indicate a similar agreement with human movement and behaviour observed in the real world. In the real world, humans were observed to move faster in same direction movement compared to opposite direction movement. In opposite direction movement humans need to perform more avoiding behaviour that can slow down the speed of movement. Although humans can perform the passing through behaviour during the opposite direction movement where they do not need to consider others during the movement, observation results (Table 5.2) show that Avoiding behaviours were more preferred by humans in the real world.

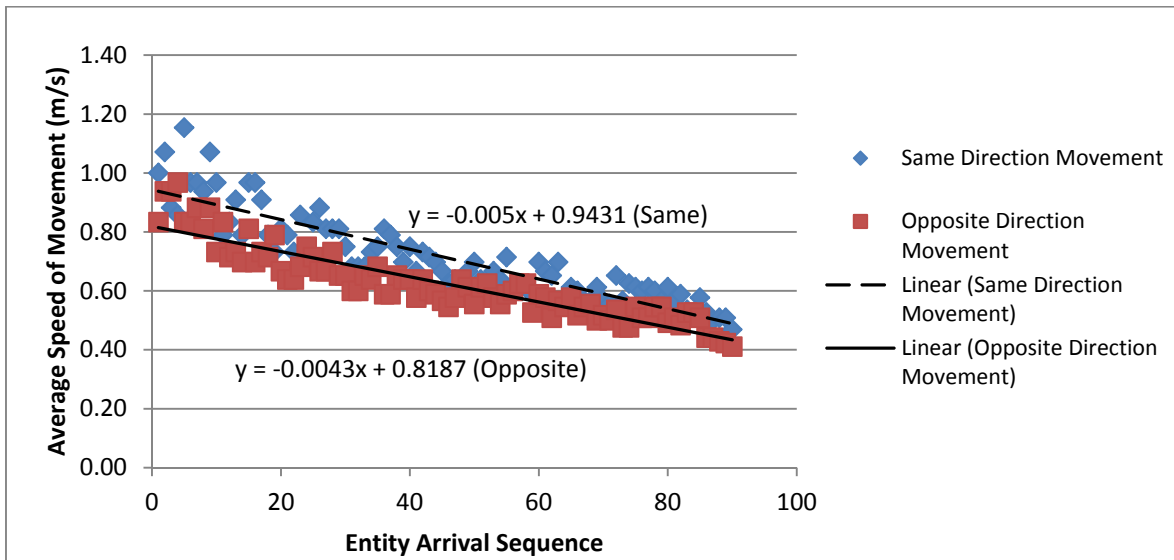


Figure 7.4 Comparison between same and opposite direction movement in high density crowd (90 Adult entities)

b. Discussion on Crowd Density for Same and Opposite Direction Movement Simulation

The parameter values of the entities that represent the initial condition are applied to simulate the movement of entities in low, medium and high density crowds for same and opposite direction movements. The simulation results show that when the number of entities is increased, the average speed of movement is decreased for all types of crowd. The results of the simulation are shown in Figures 7.5 and 7.6. Tables 7.3 show the average speeds for same and opposite direction movement with different crowd density.

The results indicate that in low density where there is greater free space available in comparison with medium and high densities, the entities are able to move around more easily. The results show that the average speeds of movement for 30 entities is considerable faster compared to the 90 entities in the same floor area. The simulation results show that space plays a significant role during the movement of entities in the virtual environment. When the number of entities is

increased the entities in the virtual environment need to compromise with the limited space and decelerate or slowdown in order to avoid other entities and reach the movement objective.

Table 7.3 *Average speeds for same and opposite direction movement with different crowd densities*

Crowd Density	Same direction		Opposite direction	
	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)
Low (30 entities)	1.15	0.75	1.11	0.70
Medium (60 entities)	1.00	0.53	1.00	0.56
High (90 entities)	1.00	0.47	0.83	0.41

The simulation reflects on the real world situation where human movement becomes slower during peak times and crowd density was observed as one of the factors affecting human movement and behaviour in the real world. The results also indicate that space is important for humans during movement. The individual in a crowd needs space to move around. Therefore, a suitable space for each individual in the real world needs to be considered during facilities design. Similar to the previous discussion, the majority of the entities move considerably faster in same direction simulation for all sizes of crowd.

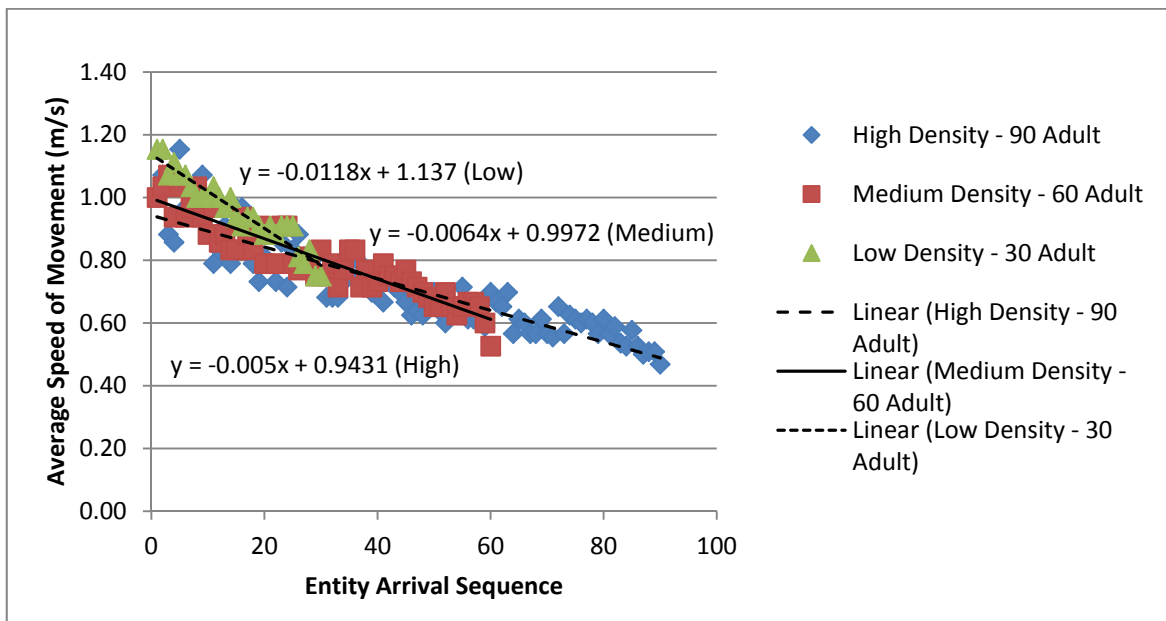


Figure 7.5 Entity Arrival Sequence versus Average Speed of Movement in low, medium and high density crowds for same direction movement simulation (Adult entities)

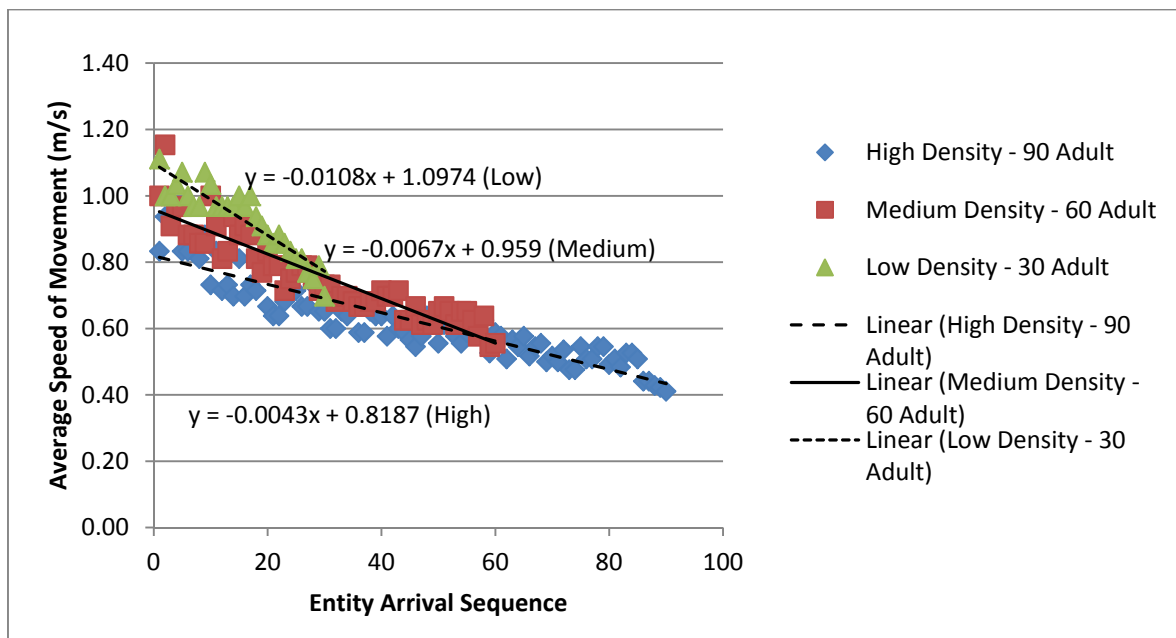


Figure 7.6 Entity Arrival Sequence versus Average Speed of Movement in low, medium and high density crowds for opposite direction movement simulation (Adult entities)

c. Discussion on the Changes in Visual Perception and Personal Space Parameters for Same and Opposite Direction Movement Simulation

The simulation is conducted to compare the changes in the visual perception and personal space parameters in comparison with the initial conditions in same and opposite direction movements (refer to Table 7.1 for detailed changes of the parameters). The results of the simulation conducted using a high density crowd are shown in Figures 7.7 and 7.8. Table 7.4 shows the average speeds of same and opposite direction movement with different scenarios in high density crowds. The results show that in high density crowds the changes in visual perception and personal space parameters affect the movement of entities in both same and opposite direction movements.

The results from Figures 7.7 and 7.8 indicate that in the virtual environment when the entities have a smaller personal space or have a more focused visual perception (in this case, smaller view arc and longer view range) compared to the initial conditions, they are able to move faster. The results show that smaller personal space and more focused visual perception contributed more space for the entities to move towards the movement objective. In the case of opposite direction movement, smaller personal space and more focused visual perception gave more time for entities to perform the avoidance angle/distance behaviour and they were able to move faster towards the movement objective.

Table 7.4 Average speeds for same and opposite direction movement with different scenarios in high density crowd

Scenario	Same direction		Opposite direction	
	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)
Initial Condition	1.00	0.47	0.83	0.41
Changes in Visual Perception	0.94	0.57	1.15	0.41
Changes in Personal Space	1.11	0.7	0.91	0.64

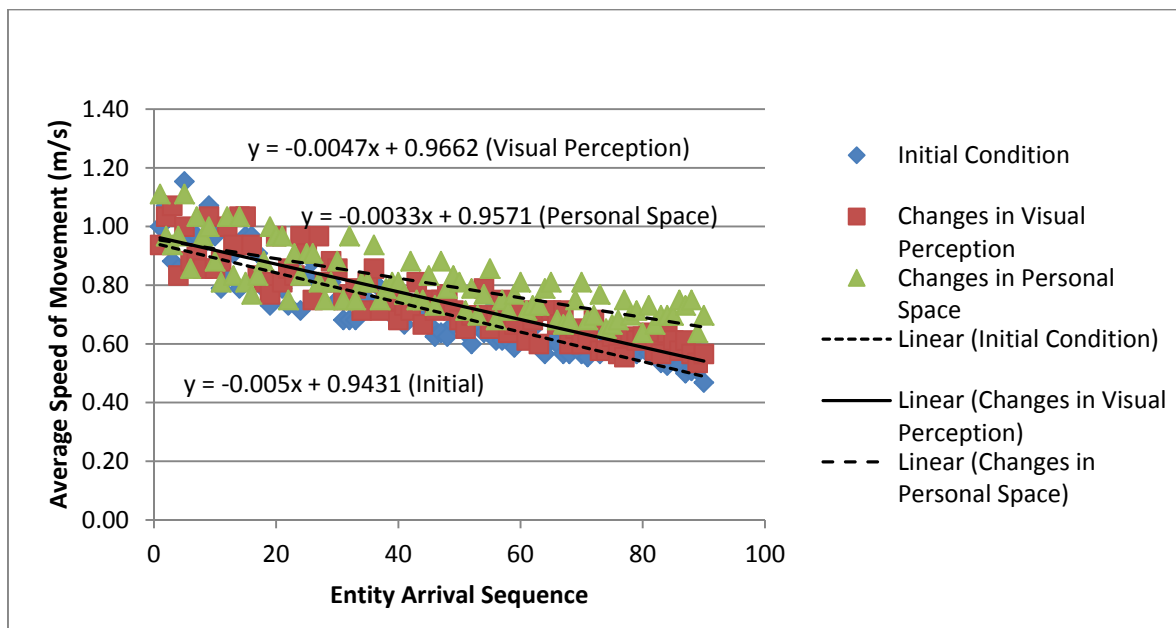


Figure 7.7 Entity Arrival Sequence versus Average Speed of Movement comparing initial condition with changes in visual perception and personal space in high density crowds (Same direction movement)

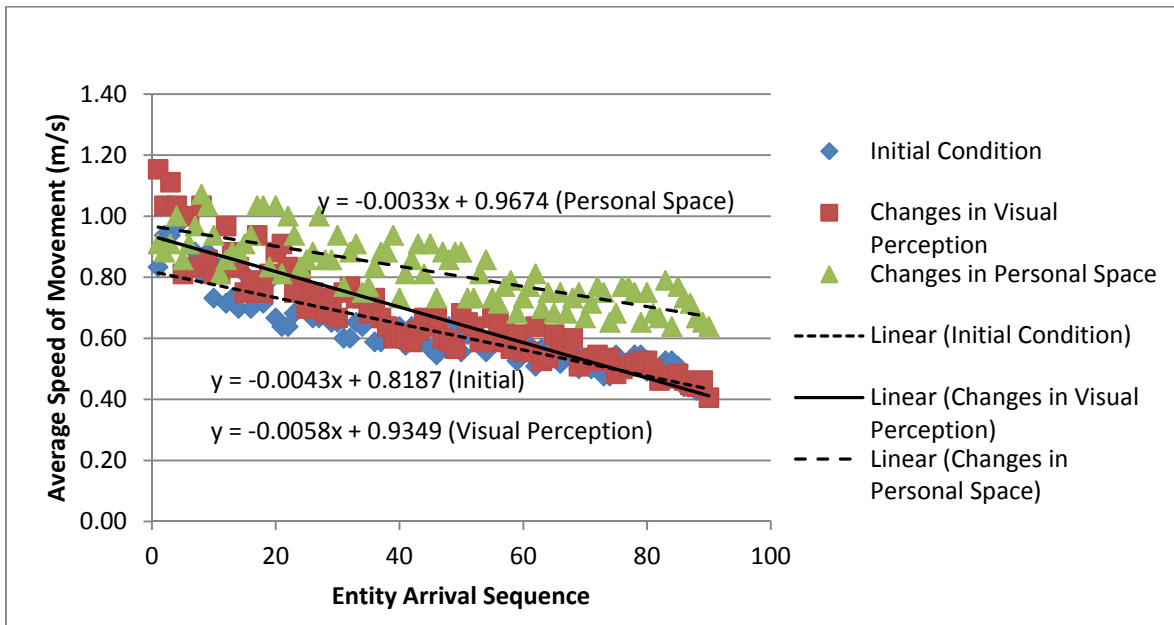


Figure 7.8 *Entity Arrival Sequence versus Average Speed of Movement comparing initial condition with changes in visual perception and personal space in high density crowds (Opposite direction movement)*

However, the changes in visual perception and personal space parameters had little effect on the average speed of movement for the entities in low density crowds compared to the initial conditions as shown in Figures 7.9 and 7.10. Table 7.5 shows the average speeds of same and opposite direction movement with different scenarios in low density crowds. Although the entities move considerably faster if there was a change in the personal space parameter, the changes in the visual perception parameter gave a lower average speed of movement compared to initial conditions (Figures 7.9 and 7.10).

The results indicate that in low density crowds, the entities already have significant space to move around the floor area. There are limited occasions when entities change the avoidance angle/distance during the movement. Therefore, changes in visual perception and personal space are not significant to the movement in low density crowd in the virtual environment.

Table 7.5 Average speeds for same and opposite direction movement with different scenarios in low density crowd

Scenario	Same direction		Opposite direction	
	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)
Initial Condition	1.15	0.75	1.15	0.75
Changes in Visual Perception	1.07	0.77	1.07	0.77
Changes in Personal Space	1.07	0.83	1.07	0.83

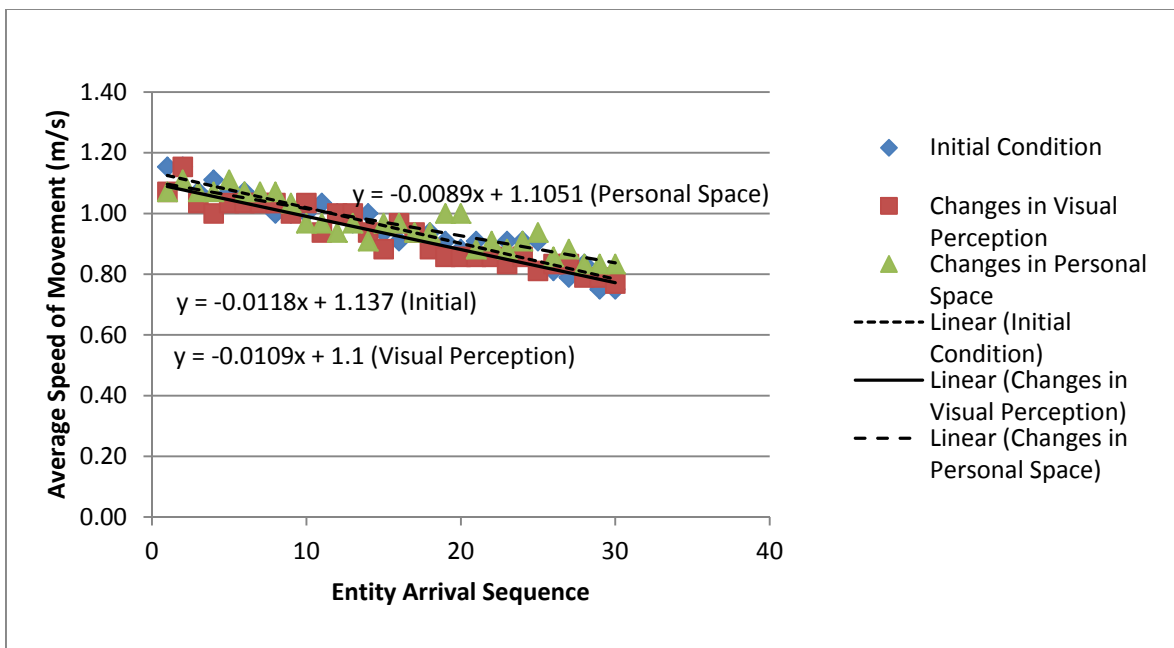


Figure 7.9 Entity Arrival Sequence versus Average Speed of Movement comparing initial condition with changes in visual perception and personal space in low density crowds (Same direction movement)

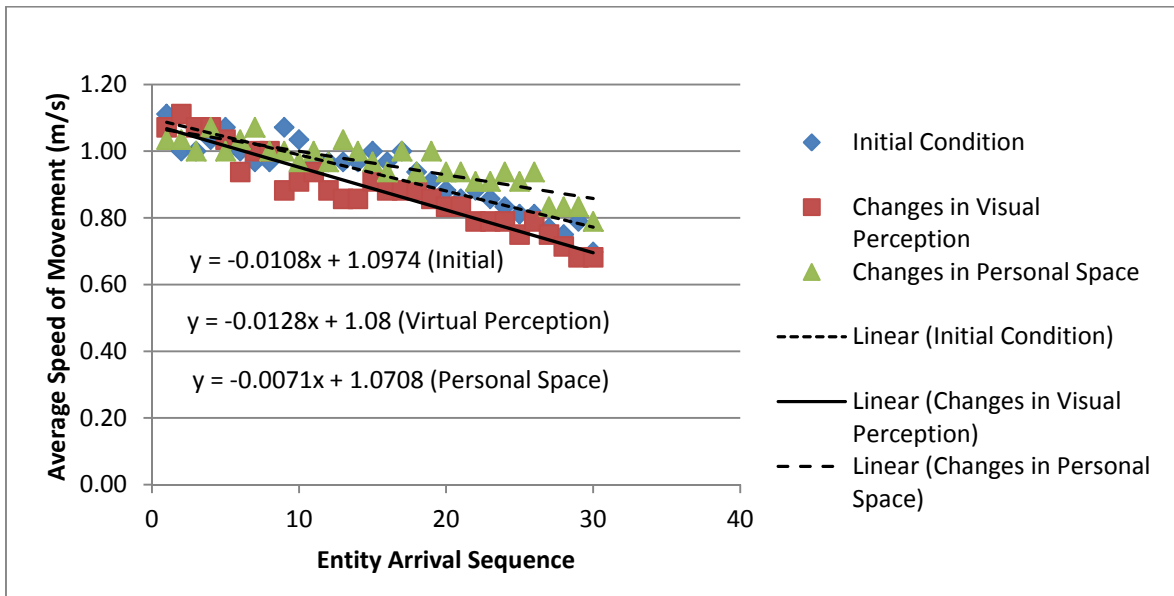


Figure 7.10 *Entity Arrival Sequence versus Average Speed of Movement comparing initial condition with changes in visual perception and personal space in low density crowds (Opposite direction movement)*

Similar to free direction movement, the simulation conducted indicated that the visual perception and personal space parameters in the virtual environment have a slightly different effect in the real world. However, there is some element of the simulation that has a similar agreement with the real world observation. Observations conducted (in the virtual environment) show that the visual perception and personal space are among the factors affecting human movement and behaviour similar to the real world. In the real world during Move-Stop-Move behaviour human speed of movement becomes slower when there is a need to look for information (decreases in virtual perception or less focus towards the movement). Besides that, humans with luggage who need more personal space to move around were observed to move slower compared to those who moved alone (decreases in personal space).

In the case of a low density crowd, humans are considered to have enough space to move around the area. Therefore, humans have more time to make any decision concerning their movement such as when to avoid humans coming from the opposite direction after perceiving them

(change the visual perception) or choose to move towards a bigger free space (maintain personal space). The condition of ‘perceive the obstacles earlier to avoid them earlier’ or ‘choose a bigger space to move in’ is sometimes difficult to observe in the real world because it involves fast decision making in the human although the situation can be experienced during the movement in a real crowd.

d. Discussion on the Different Ratios of Older Entities in Same and Opposite Direction Movement Simulation

This simulation is conducted to compare the involvement of older entities in a crowd. The movement of 90 entities (representing a high density crowd) and 30 entities (representing a low density crowd) in the initial condition were selected for the simulations. The number of older entities involved in the simulation was selected based on the ratios of 20%, 50% and 80% of the total entities. The 20% of total entities is equal to 18 entities in the high density crowd and 6 entities in the low density crowd. The 50% of total entities represents 45 entities in the high density crowd and 15 entities in the low density crowd while the 80% of total entities represents 72 entities in the high density crowd and 24 entities in the low density crowd.

The simulation results are shown in Figures 7.11 to 7.14 and show that when the number of older entities is lower, the movement of the entities in the crowd becomes faster. The involvement of the older entities affected the overall movement in both same and opposite movement directions and in low or high density crowds. Tables 7.6 and 7.7 show the average speeds with different ratios of older entities in high and low density crowds respectively.

Table 7.6 *Average speeds for same and opposite direction movement with different ratios of older entities in high density crowd*

Ratio of Older Entities	Same direction		Opposite direction	
	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)
20 % [18 people]	1.00	0.47	0.94	0.39
50 % [45 people]	0.86	0.43	0.91	0.29
80 % [72 people]	0.88	0.36	0.86	0.33

Table 7.7 *Average speeds for same and opposite direction movement with different ratios of older entities in low density crowd*

Ratio of Older Entities	Same direction		Opposite direction	
	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)	Average speed - first arrival (m/s)	Average speed - last arrival (m/s)
20 % [6 people]	1.11	0.57	1.03	0.57
50 % [15 people]	1.07	0.60	1.00	0.54
80 % [24 people]	1.03	0.50	1.03	0.52

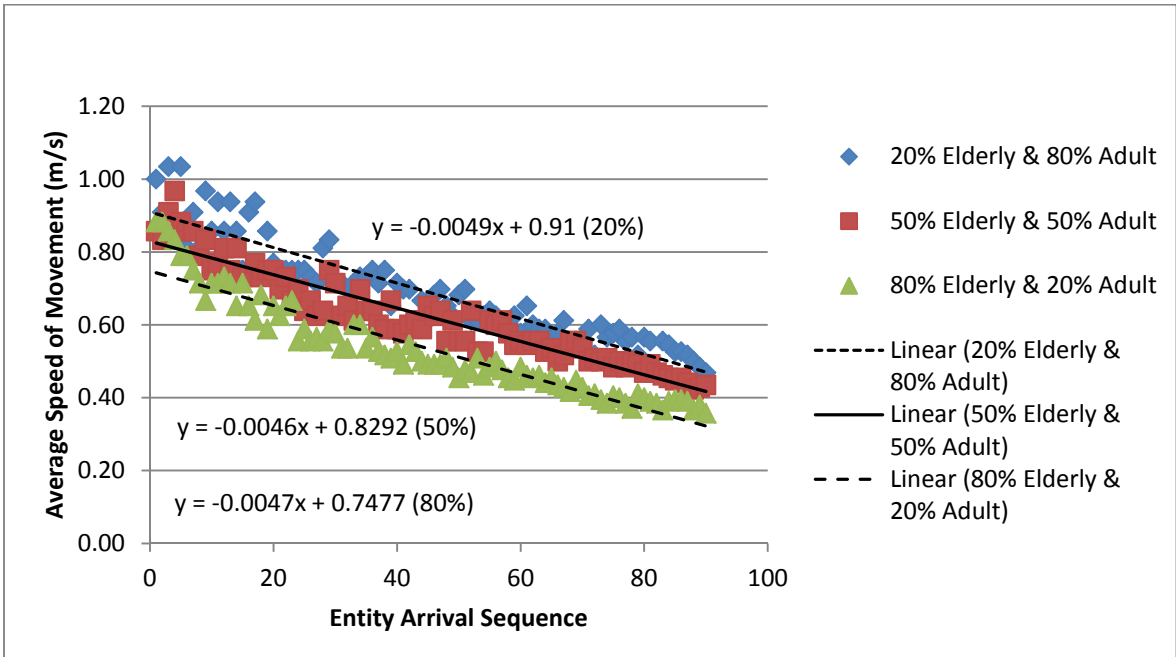


Figure 7.11 Entity Arrival Sequence versus Average Speed of Movement comparing 20%, 50% and 80% older entities in high density crowd (Same direction movement)

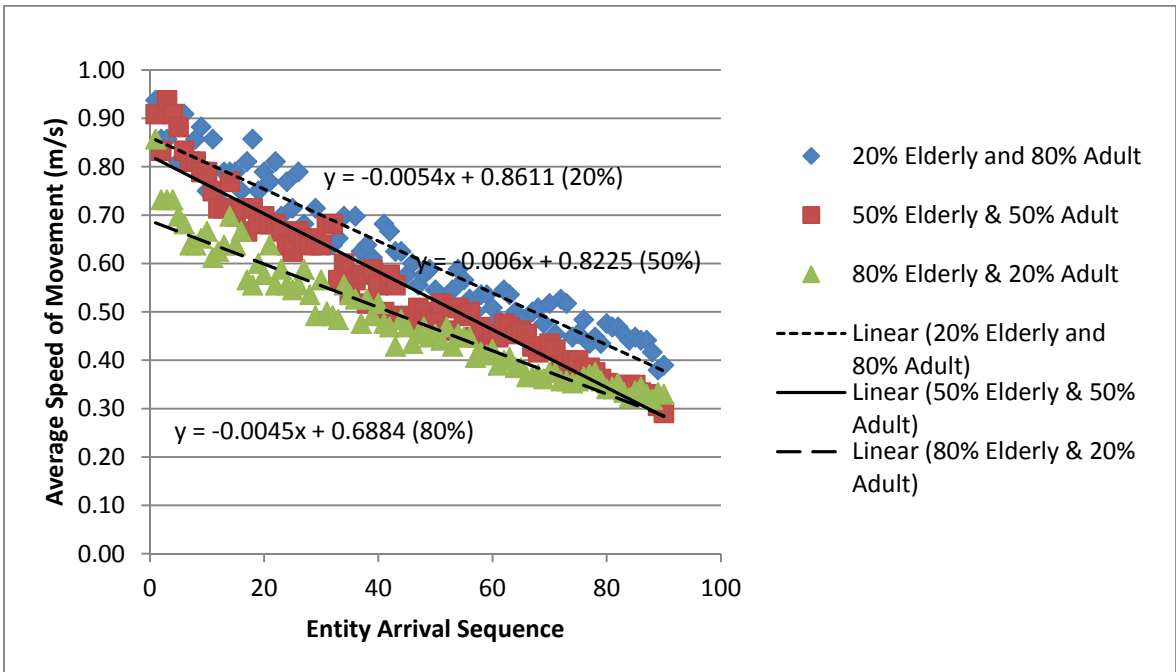


Figure 7.12 Entity Arrival Sequence versus Average Speed of Movement comparing 20%, 50% and 80% older entities in high density crowd (Opposite direction movement)

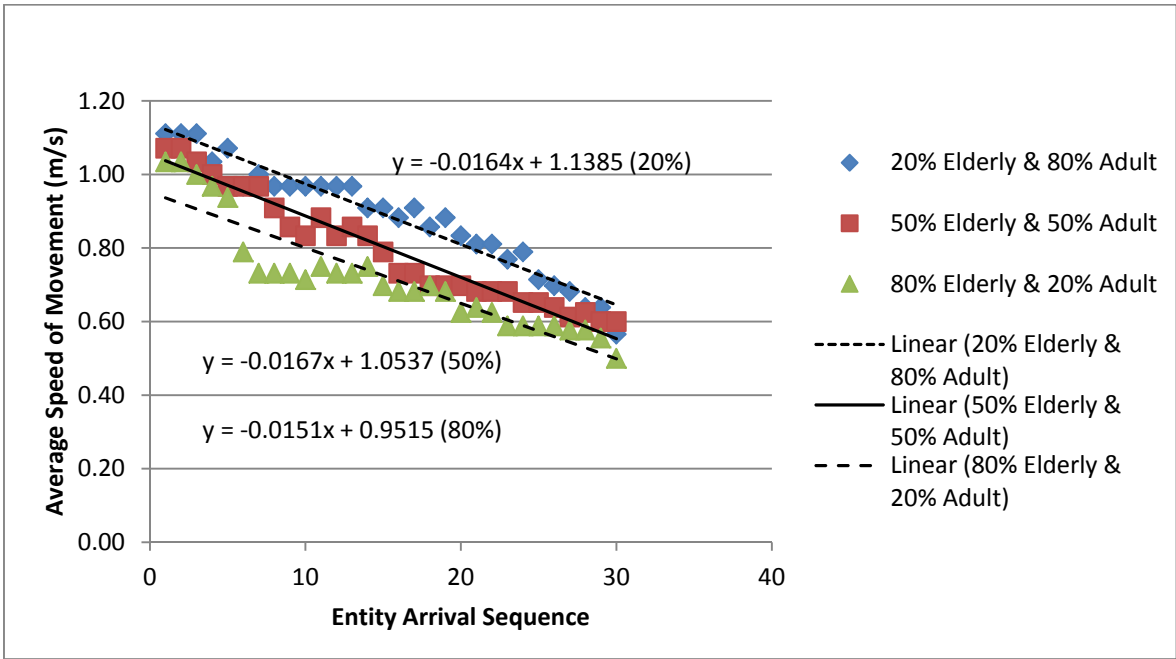


Figure 7.13 Entity Arrival Sequence versus Average Speed of Movement comparing 20%, 50% and 80% older entities in low density crowd (Same direction movement)

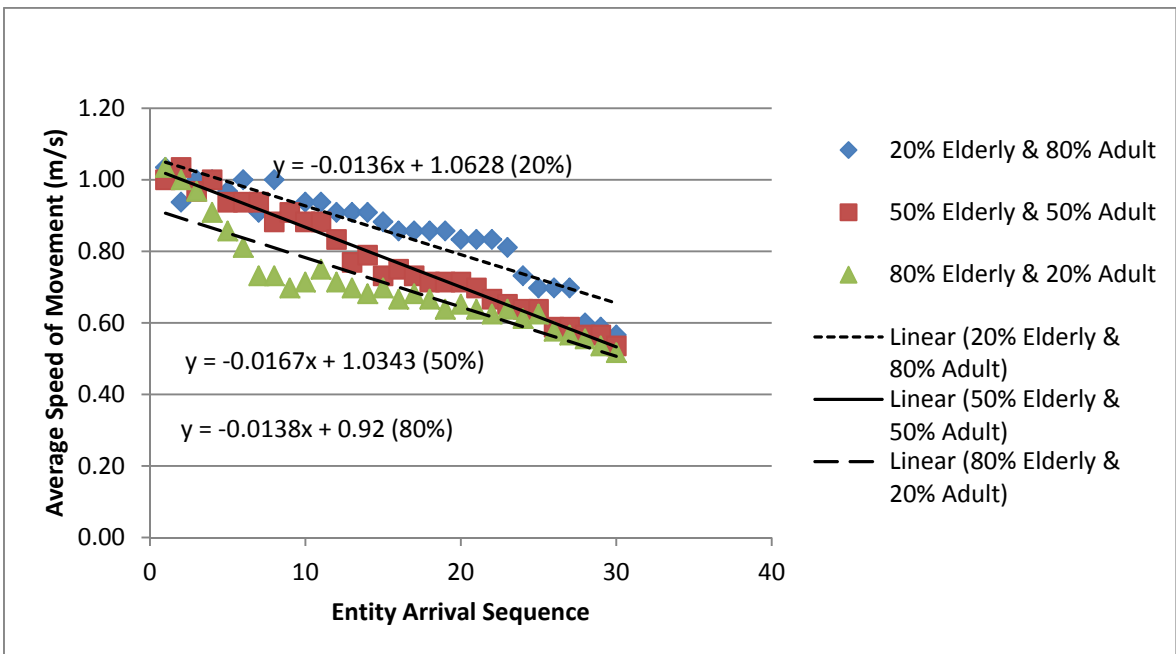


Figure 7.14 Entity Arrival Sequence versus Average Speed of Movement comparing 20%, 50% and 80% older entities in low density crowd (Opposite direction movement)

The number of older people observed in the recorded video is considered to be limited. Therefore, it is difficult to specifically show correlation between the simulation results and the observation studies. However, when the simulation results are compared with the literature survey or other research work, the simulation results can be considered sufficient to represent human movement and behaviour in the real world focusing on older people. In the real world, most older people move with a slower speed and larger personal space. This is due to physical limitations (physiological factors), where they need to balance their physical ability and the requirement for more time for making any decision related to the movement.

In some cases the older people are observed performing more Passing Through behaviour during the opposite direction movement. It means that older people tend not to consider others during the movement. This might be due to the inability of their visual perception to perceive others earlier during the movement. Therefore, other humans need to move carefully to avoid any collision with older people and this affects the overall speed of movement of the crowd. Movement of older entities in low and high density crowds can also create queuing and competitive behaviour between the adult entities. A detailed discussion of queuing and competitive behaviour of adult entities is given in the next section.

e. Discussion on Queuing and Competitive Behaviour in Same Direction Movement Simulation

The movement of entities in same direction movement with 80% older entities and 20% adult entities has been extracted from the graph and shown in Figures 7.15 and 7.16. The results indicate that during movement in a crowd, the older and adult entities performed the queuing and competitive behaviours. The Queuing and Competitive behaviours of the entities in the virtual

environment can be observed through the direct observation of the simulation and the distribution of older and adult entities from the graph.

Figure 7.15 shows the movement of entities in a low density crowd. The results show that during the movement in low density, the adult entities compete with the older entities and all (adult entities) arrived at the end point earlier than (or faster than) the older entities. However, in high density crowds as shown in Figure 7.16 only 9 adult entities or 50% of the total adult entities (18 entities) manage to arrive at the end point earlier than (or faster than) the older entities. Another adult entity was observed moving in between (or slower than) the older entities and the arrival sequence is shown using red arrows in Figure 7.16.

The simulation and observation results indicate that in the virtual environment during movement in a low density crowd, when there is enough space to move towards the end point (personal objective parameter), the entities will move faster. The entities will compete with other entities (Competitive behaviour). However, when a high density crowd is encountered and where the space is limited for movement or competition with other entities, the adult entities will follow the crowd or even queue with the crowd (Queuing behaviour).

The results from the simulation show similar movements and behaviours as found in the real world situation. In the real world, on some occasions adults tend to move faster than older people. However, when there is not enough space to compete or overtake (Competitive behaviour) and the older people are at the front, adults will follow the trail (Queuing behaviour). Besides that, the simulation results and real world observations prove that the Competitive and Queuing behaviour can occur in any area of the crowd and are not limited to the bottleneck exit door. Slow movement and stopping in the middle of the movement (Move-Stop-Move behaviour) is an example of a situation that can become an obstacle towards movement flow in crowd and contributes to the Competitive and Queuing behaviours.

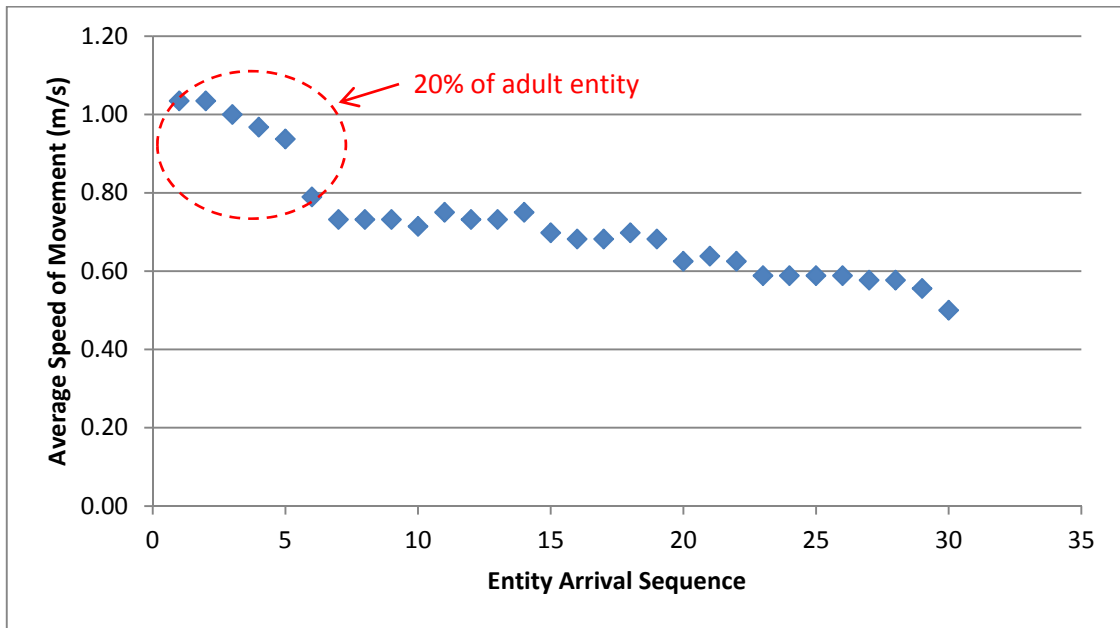


Figure 7.15 Arrival sequence of 20% adult entities (6 entities) in low density crowd

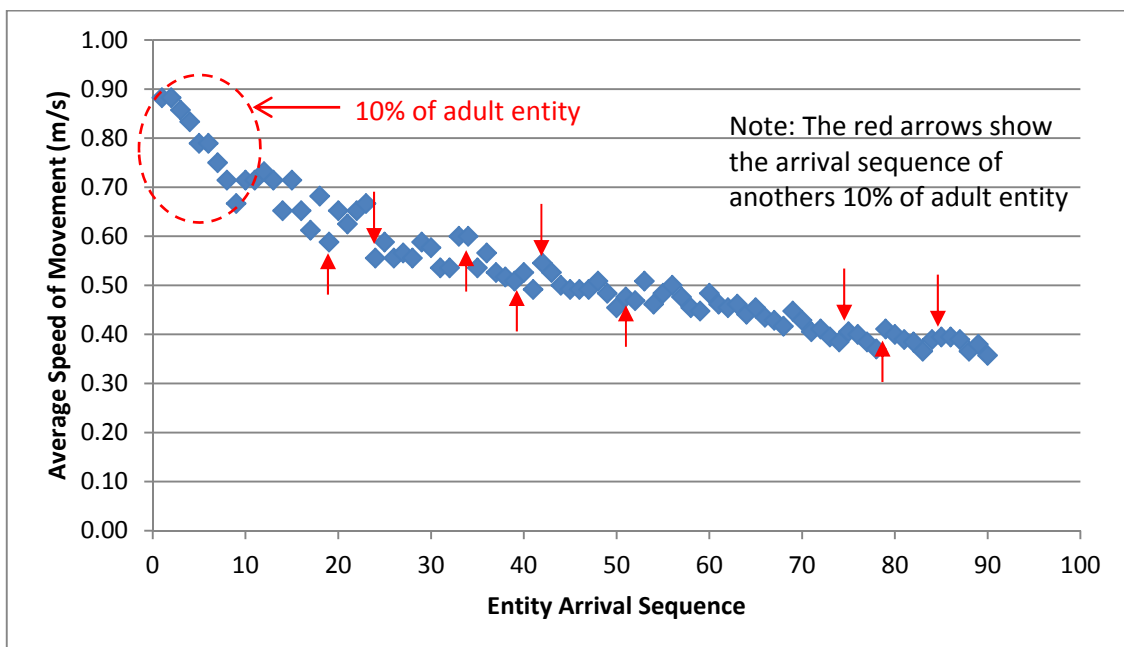


Figure 7.16 Arrival sequence of 20% adult entities (18 entities) in high density crowd

f. Discussion on Emergency Situation for Same and Opposite Direction Movement Simulation

In emergency situation simulation, the movement of entities is set to be faster than the normal situation. Although the average speed of movement for an emergency situation is expected to be higher than the initial condition there are several observations conducted in an emergency situation. Figure 7.17 shows the movement of 80% older entities (72 entities) and 20% adult entities (24 entities) in a high density crowd during an emergency situation. The results show that the 20% of adult entities in the simulation moved faster and arrived earlier at the end point compared to older entities. The results indicate that in emergency situations the adult entities will find any space available to move towards the movement objective. There are no adult entities that moved slower than older entities as shown in Figure 7.16 previously.

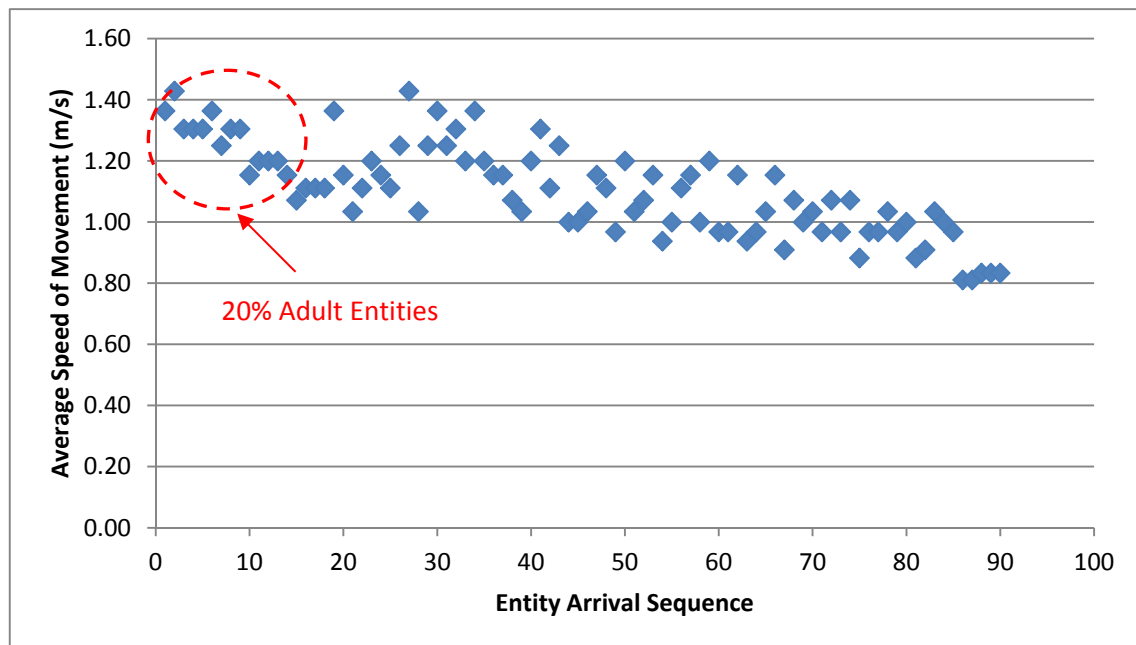


Figure 7.17 Average Speed of Movement for 80% older entities and 20% adult entities (High density crowd)

The emergency situation conducted in this section is considered as an example of an application using the software. Since the observation studies conducted in this research are concerned with the normal situation, the emergency simulation conducted can be considered as another case study for the research work. Although there is a need to conduct further research to understand the emergency situation, the simulation shows that the software is a promising tool to predict different situations of the crowd. It is also beneficial to predict the effect of different facilities layout towards human movement and behaviour conducted in the next section.

7.4 Case Studies

The case studies were conducted with the objective of showing the effectiveness and usefulness of the simulations. The case studies start with simulating the observational area, the Stesen Sentral. Different types of scenarios and layouts were examined to demonstrate the ability of the software as a design tool. The simulation using the Stesen Sentral also attempted to understand the effect of selected parameters when applied in different layouts since the software validation conducted only focused on the 'empty design'.

Besides the Stesen Sentral (multi-mode transportation system), bottleneck and non-bottleneck layouts which are different from the observational area were also conducted. This was to show how different layouts can be used to predict human movement in the real world. However, the validation of the case studies is only conducted by observing the entities movement within the virtual environment. Comparison between the simulations in case studies with the real world movement has not been possible in this research work.

7.4.1 Multi-mode Transportation System Simulation

The multi-mode transportation system simulation is conducted to evaluate different building layouts and the effects of obstacles on the movement of entities in a crowd. The three major discussions conducted for the multi-mode transportation system simulation include the results of different layouts, the effects of different obstacles and changes to the personal space parameter during the simulation.

a. Discussion on Different Layouts for Multi-mode Transportation System Simulation

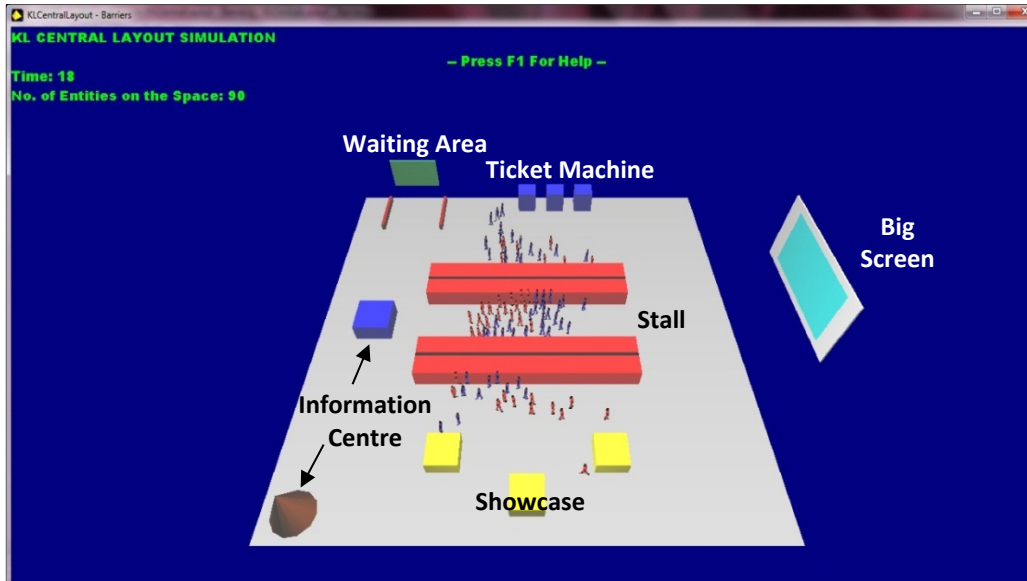
Two different layouts were developed to represent the multi-mode transportation system as shown in Figure 7.18. The layout consists of a ticket machine, waiting area, information centre, big screen, showcase area and stalls. The layouts were developed based on the observation area at the Stesen Sentral, Kuala Lumpur with some modification on the arrangement of the stall and showcase area.

In Layout 1 the arrangement of the stalls is in two rows where the middle of the stalls created a limited space for the entities to move around while the showcase area is arranged in two rows. On the other hand, in Layout 2 the stalls were arranged in four locations while the showcase area is arranged as a single row. The simulation was conducted to compare the effect of different layouts on the movement of entities in the multi-mode transportation system (shown in Figure 7.19). For Layout 1, the first and last entities arriving at the movement objective moved with average speeds of 0.97 m/s and 0.53 m/s respectively. For Layout 2, the first and last entities arrived at the movement objective with average speeds of 0.86 m/s and 0.60 m/s respectively. The results show that the entities move slightly faster in Layout 1 compared to Layout 2.

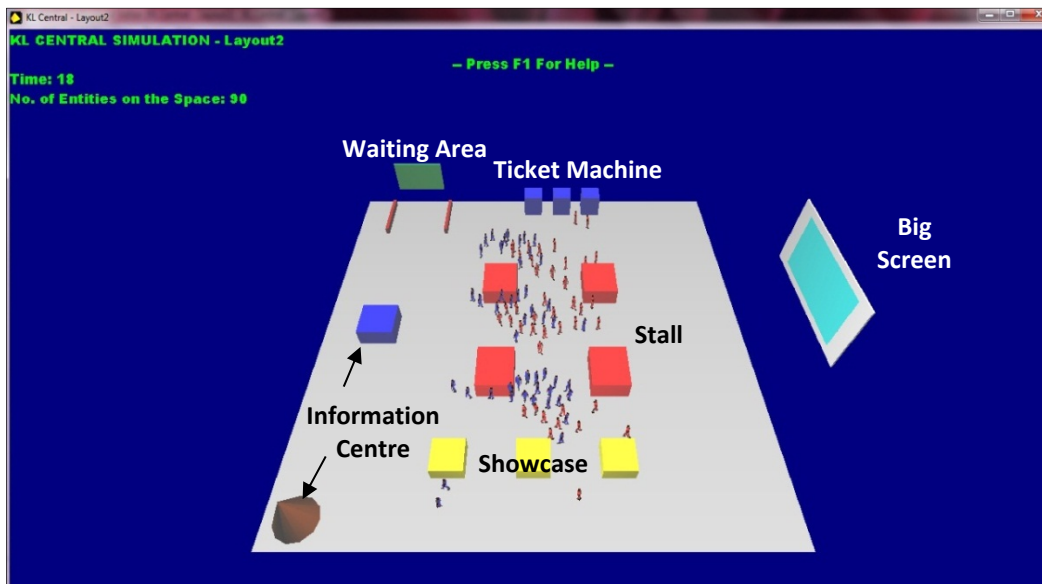
The results indicate that the movement of entities in Layout 2 resulted in more avoidance behaviour compared to the movement of entities in Layout 1. Although a bottleneck area appeared in Layout 1 (the area between the stalls), the bottleneck area was observed to support the rearrangement of the entities' movement. Therefore, the entities are observed to follow more structured movement after avoiding each other compared to Layout 2. In Layout 2, more time is available for the entities to avoid each other.

The results shows that the simulation is useful in visualizing different possible layouts of facilities or building before real construction or modification is undertaken. This can save time and cost in examining new ideas for improvement or innovation in design. The simulation software is

also able to predict the effect of different layouts on human movement and behaviour in the crowd. The factors affecting human movement and behaviour obtained from the simulation are useful as an input for crowd research. The simulation also can be used to confirm the crowd observation conducted from the real world.



(a) Layout 1



(b) Layout 2

Figure 7.18 Different layouts for a multi-mode transportation system simulation

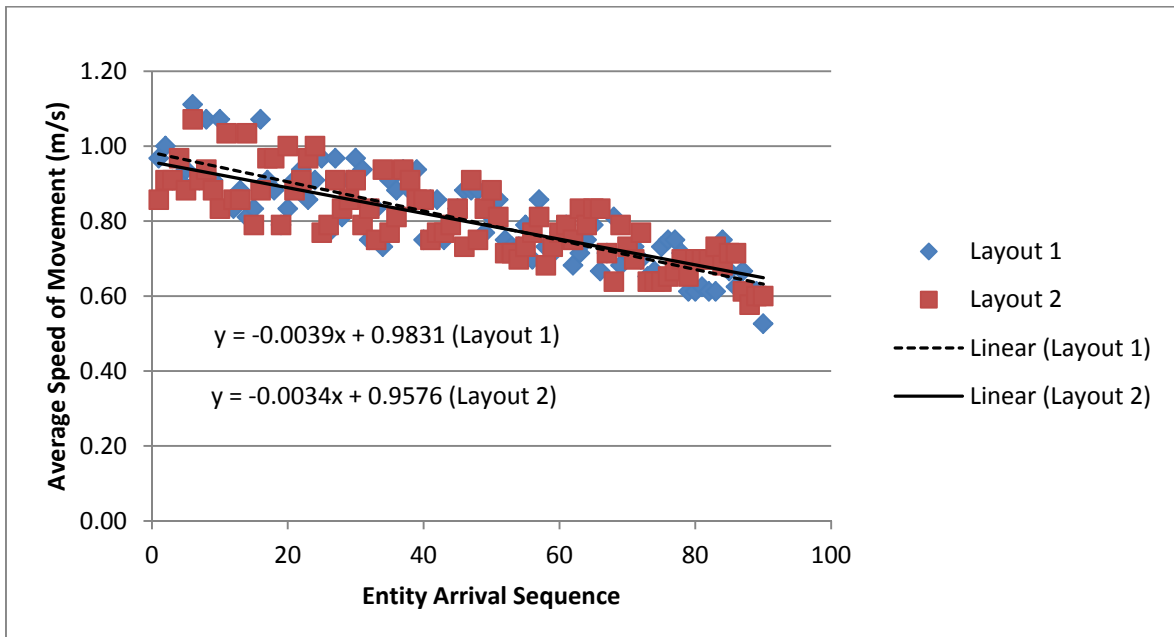


Figure 7.19 Comparison between Layout 1 and Layout 2 for a multi-mode transportation system simulation

b. Discussion on Barriers as Obstacles in a Multi-mode Transportation System Simulation

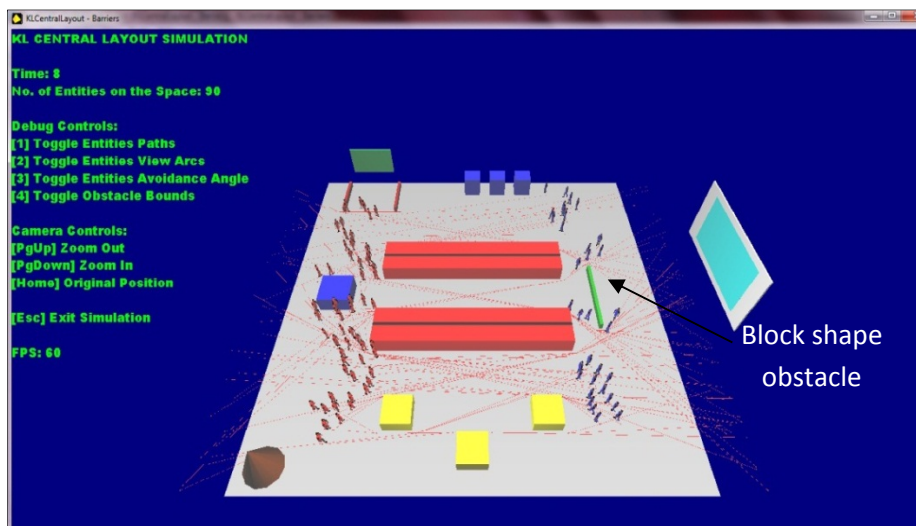
Two different barriers were selected as obstacles to control the movement of entities in the simulation. The barriers are designed as block and sphere shapes as shown in Figure 7.20. The simulation is conducted to evaluate the movement of entities with and without the obstacles. Teknomo (2002) indicated that sometimes by introducing a barrier, crowd movement can improve. The results of the simulation are shown in Figure 7.21.

The first and last entities arrived at the movement objective with the block obstacle moved with average speeds of 1.07 m/s and 0.56 m/s respectively. For the sphere obstacle situation, the first and last entities arrived at the movement objective with average speeds of 0.86 m/s and 0.6

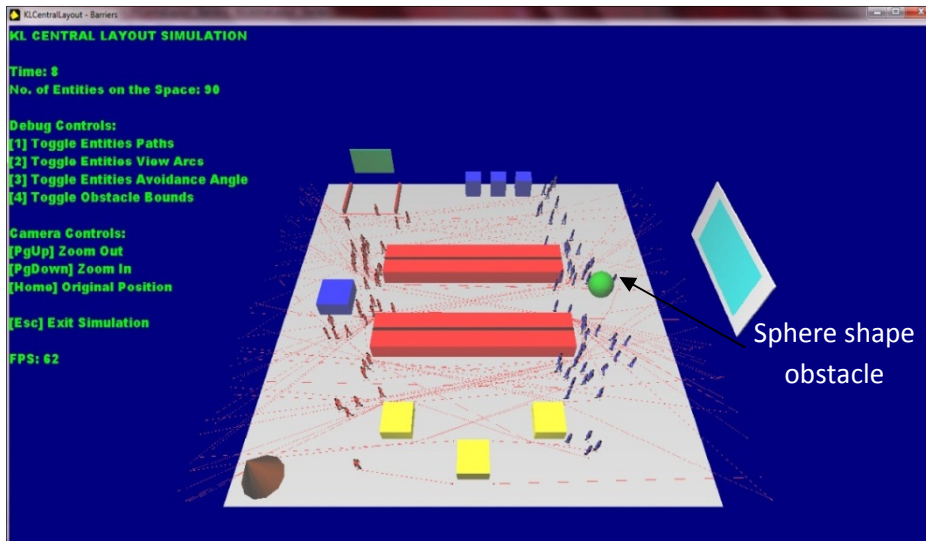
m/s respectively. Lastly, the first and last entities arrived at the movement objective without an obstacle moved with average speeds of 0.97 m/s and 0.53 m/s respectively.

Using the linear regression graph, the block and sphere obstacles constructed within the multi-mode transportation system gave similar simulation results although the spherical obstacle improved the crowd movement (based on observation). However, movement without obstacles provided better results. The results indicate that the simulation conducted is useful as a tool for crowd traffic control.

Traffic control is important task to control the human movement or crowd flow to avoid overcrowding especially at focused areas or facilities such as train stations, stadia exit doors, etc. In some cases, crowd traffic control only needs very limited actions such as placing a barrier in the movement area or developing one way paths for pedestrians to make crowd movement more efficient. Although the two examples given did not provide a significant result, different ways of crowd traffic control can be examined through the software in a short time.



(a) Block obstacle in the movement area



(b) Sphere obstacle in the movement area

Figure 7.20 Block and Sphere obstacle in a multi-mode transportation system layout

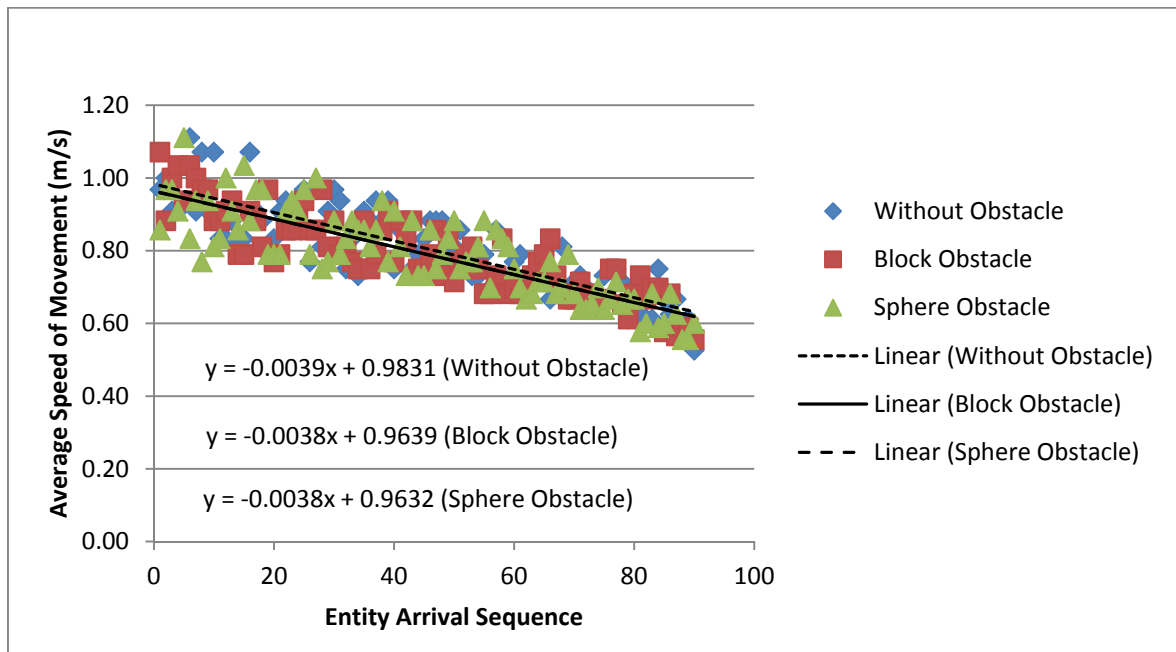


Figure 7.21 Comparison between Block and Sphere obstacle in a multi-mode transportation system layout

c. Discussion on the Changes of Personal Space Parameter Value for Multi-mode Transportation System Simulation

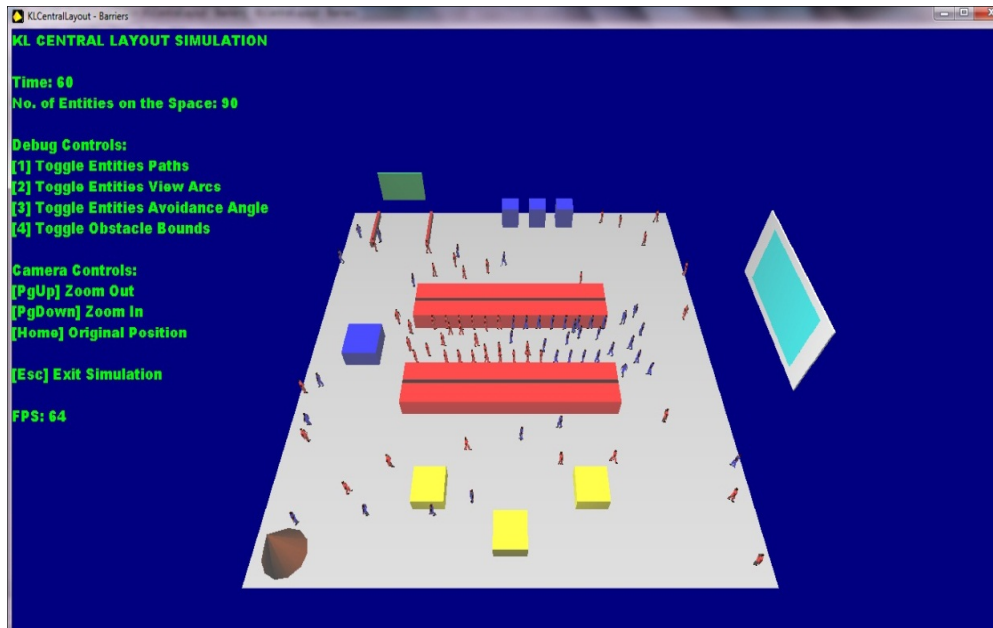
The personal space parameter for the entities in the multi-mode transportation system was changed to represent the movement of entities with bigger personal space. Other parameters were maintained at the values shown in Table 7.1. The simulation was conducted for three minutes and an overview of the simulation is shown for each minute in Figure 7.22.

The simulation shows that when the personal space parameter is changed to 0.5 m, the simulation fails as the entities become trapped in the middle of the space. The area in the middle of the layout becomes a bottleneck for the entities and prevents them moving towards the end point (Personal Objective parameter). Additionally, entities are also observed to be trapped at the edge of the space where the entities try to avoid each other during the movement. The simulation indicates that during the movement of the entities in the building design, the size of personal space can also affect the movement of entities. Therefore, a suitable personal space parameter should be selected for the building design simulation.

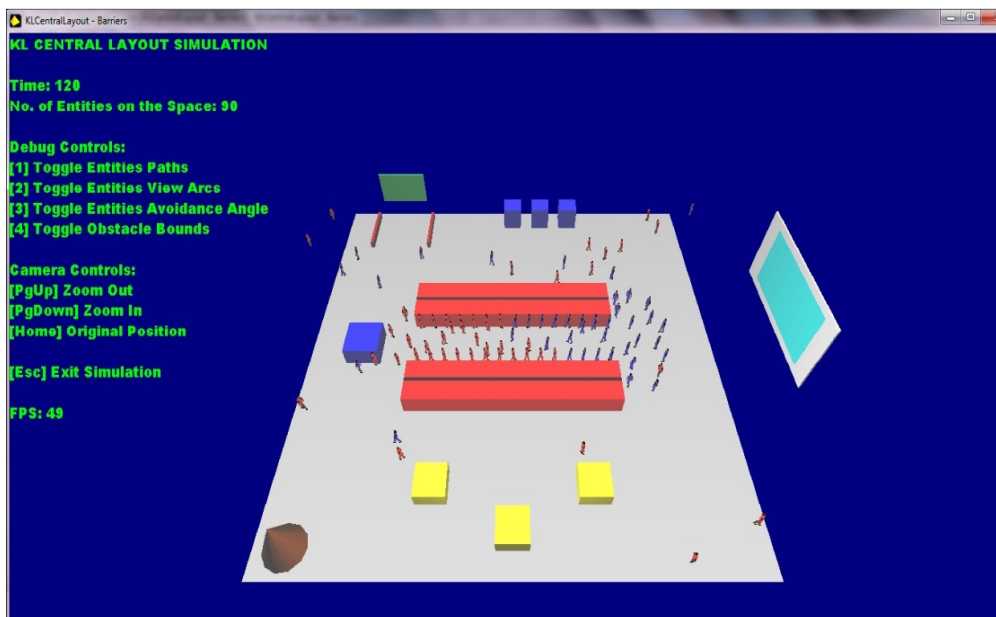
The simulation conducted was considered to not reflect movement and behaviour of humans in the real world. Human movement and behaviour in the real world is flexible where humans can adjust their personal space accordingly based on the crowd density. In high density crowds humans can tolerate moving with a smaller personal space to avoid colliding with others. However, older people and those with disabilities have a difficulty in adjusting their personal space compared to adults and able-bodied people.

An elderly man with stick or a disabled person in a wheelchair are examples of people that should be considered during the movement. The simulation conducted can be visualised as the movement of these people where they always maintain their personal space during the movement

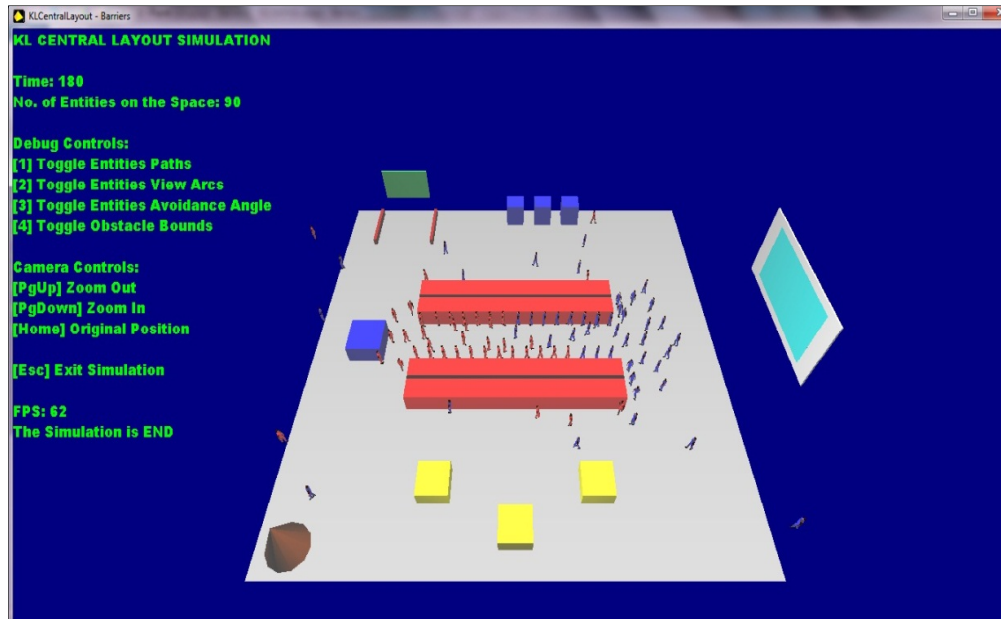
due to their limitations. The simulation indicates that when there are many people that cannot tolerate a reduction in personal space or take some time to adjust their personal space there is the possibility of a jamming situation. It can be concluded that the simulation is feasible and useful to predict the changes of personal spaces related to different facilities layout.



(a) Movement of 90 entities at 60 seconds



(b) Movement of 90 entities at 120 seconds



(c) Movement of 90 entities at 180 seconds

Figure 7.22 Movement of entities with 0.5 m of personal space

7.4.2 Bottleneck and Non-Bottleneck Layout Simulation

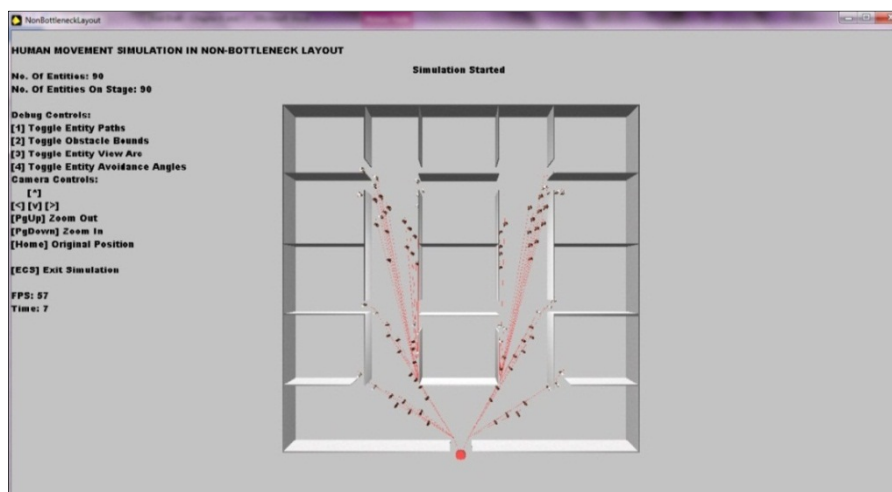
The bottleneck and non-bottleneck layout simulations are conducted to evaluate the effect of bottlenecks and non-bottlenecks on the movement of entities in a crowd. The major difference of this simulation compared to the multi-mode transportation system is the focus more on the evacuation process from buildings such as offices. The bottleneck and non-bottleneck layout simulation is conducted for three minutes where the time taken for each entity to move towards the selected destination and total time taken for all entities to evacuate the layout are the outputs of the simulation.

a. **Discussion of Evacuation Simulation from Bottleneck and Non-Bottleneck Layouts**

The simulations are conducted to understand the effects of bottleneck and non-bottleneck layouts on evacuation of the space. 90 adult entities were randomly allocated to initial positions within the two layouts and the simulation showed their movement towards the exit door marked by a red circle in Figure 7.23. During the simulation, the evacuation time for each entity was recorded and the results of the evacuation time from the bottleneck and non-bottleneck layouts were compared as shown in Figure 7.24.



(a) *Bottleneck layout*



(b) *Non-bottleneck layout*

Figure 7.23 *Evacuation of entities in bottleneck and non-bottleneck layout*

The simulation results show that the total evacuation time with the bottleneck layout is higher compared to total evacuation time for the non-bottleneck layout. Although the fastest entities evacuate from both layouts in 10 seconds, entities in the bottleneck layout needed a total of 51 seconds to evacuate from the area while only 36 seconds was needed to evacuate the non-bottleneck layout. Additionally, the linear regression line (Figure 7.24) indicates that entities evacuate in a more structured manner from the non-bottleneck layout when compared to evacuation from the bottleneck layout.

The results show that the simulation is useful in providing information on crowd evacuation for crowd safety. The simulation conducted for example indicates that a non-bottleneck layout provides a safer environment in terms of human movement in crowded areas. The simulation is also useful to predict how human evacuate if there is only one exit door available for the evacuation process. The simulation can also be enhanced in the future by providing other obstacles in the design such as furniture (table, chair, etc.) to examine the effect of interior design or arrangement on human movement and behaviour during evacuation.

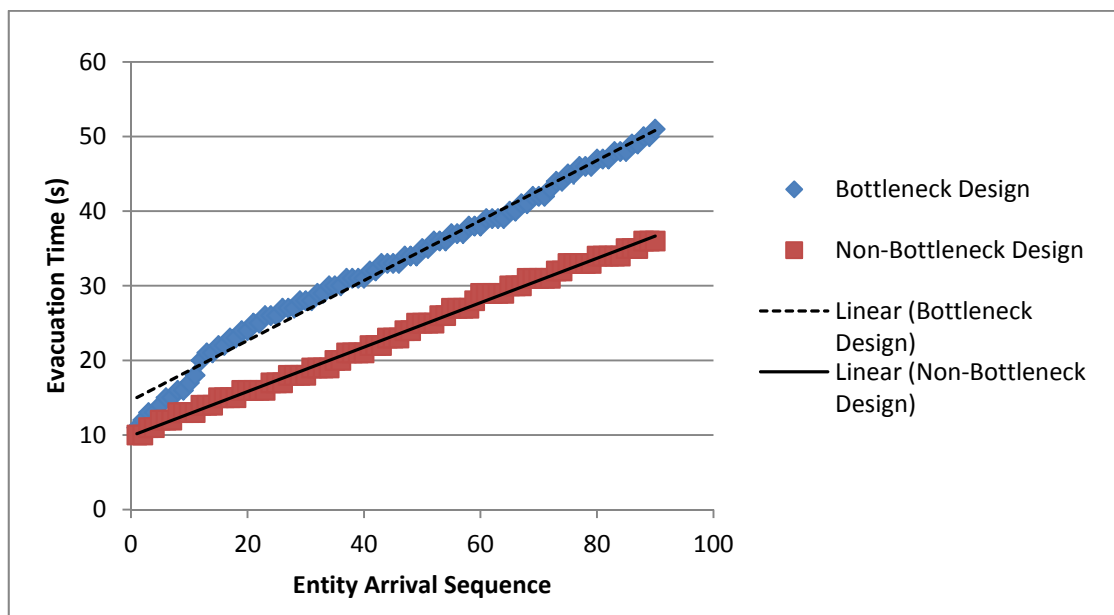
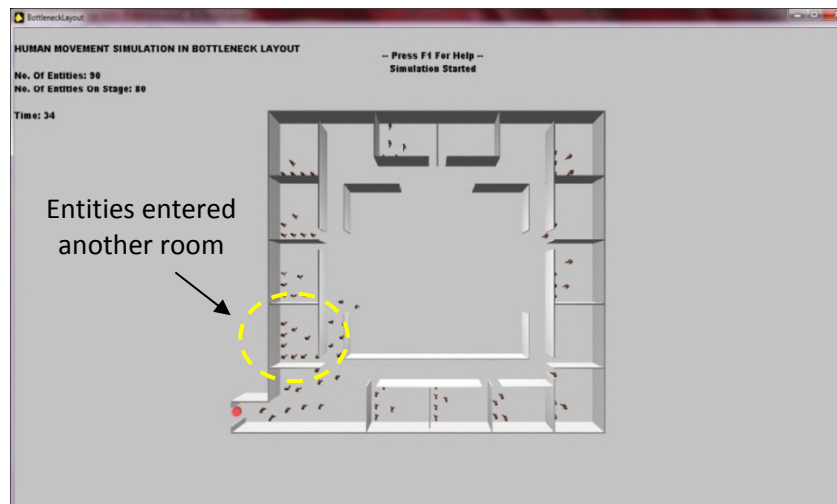


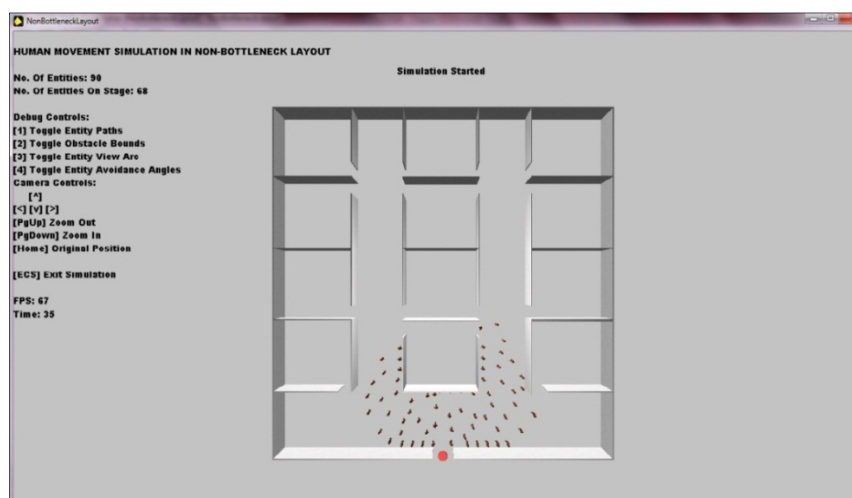
Figure 7.24 Evacuation time from bottleneck and non-bottleneck layout

b. Discussion on the Changes in Personal Space Parameter Value for Bottleneck and Non-Bottleneck Simulations

These simulations were conducted to observe the movement of entities in bottleneck and non-bottleneck layouts with changes in the personal space parameter. The personal space parameter was changed from 0.25 m to 0.5 m for each entity and the simulation was conducted with 90 entities. The entities were randomly allocated in the building area with each room initially having 5 or 6 entities. An overview of the simulation is shown in Figure 7.25.



(a) Bottleneck layout



(b) Non-bottleneck layout

Figure 7.25 *Effect of personal space parameter towards entities movement in bottleneck and non-bottleneck layouts*

The simulation shows that when the personal space parameter is changed to 0.5 m the entities cannot evacuate from the bottleneck layout. The entities become trapped in the room area. Besides this, entities were also observed to enter another room at the bottleneck area (marked by a yellow circle). The situation makes the room become too crowded and the entities cannot move around. On the other hand, in the non-bottleneck layout the entities manage to evacuate the building. However, the entities were observed to maintain the size of their personal space and the movement became slower. As shown in Figure 7.26, an evacuation with a personal space of 0.5 m took three times longer to evacuate than the initial condition.

The results show that the simulation is useful in predicting the effect of different personal spaces during the evacuation process. The contribution of the simulation conducted here was similar to the discussion of the multi-mode transportation system (a detailed discussion was presented in Section 7.4.1c). However, this simulation provides understanding that humans will find an alternative route to escape during the evacuation process. If there is not enough space to move or there is limited information about the exit door, there is a high possibility of missing the exit door during the evacuation process.

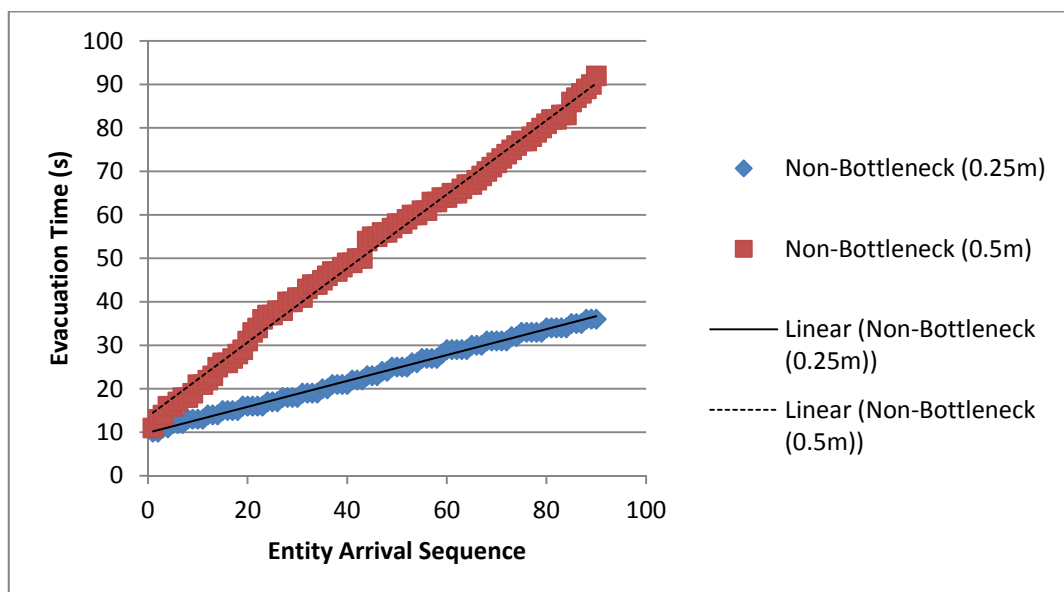


Figure 7.26 Evacuation time from non-bottleneck layout with different personal space parameter values

7.5 Validations and Limitations

In this research work, two types of simulations were conducted; software validation and case studies. The software validation focused on the lower levels of the simulation and attempted to understand the advantages and limitations of the software. Besides, the software validation is used to compare the simulation results with the real world situation to provide better insight towards human movement and behaviour.

The software validation results indicated that visual perception and personal space parameters applied in the simulation were ‘not flexible’ or not adaptively controlled by the virtual entities. The situation is thoroughly different from the ability of humans in the real world where they can control their visual perception and personal space in any situation. The representation of visual perception and personal space in the simulation is considered one of the limitations of the software.

However, in software validation it is notable that the simulation provides significant results to represent closely similar movement and behaviour of humans in the real world. For example, the simulation was able to demonstrate the situation where humans move considerably faster in same direction movement when compared to opposite direction movement, low density crowds provide more space for humans to move around, higher numbers of older people will affect the movement and behaviour of others, etc.

The software validation provides important input to support the argument that the developed software has some kind of agreement with the real world movement and behaviour. Therefore, case studies were conducted as an application of the software. The case studies attempted to replicate the movements and behaviours of the humans at the observational area, the Stesen Sentral as shown previously in Figure 6.15.

The simulation was also applied to predict different types of movement in different building layouts. Although the real world validations of the case studies were not possible in this research work, the simulation provides a promising input as a tool to validate the building layouts. For example, the simulation using bottleneck layout provides similar movement and behaviour as humans in the real world as shown in Figure 7.27. The picture was taken from another video conducted in early stage of this study. In the real world, humans at the bottleneck needed to adjust their speed of movement and perform Queuing or Competitive behaviour.



Figure 7.27 Movement of humans and entities at the bottleneck layout

7.6 Summary

This chapter presented the simulation results and analysis conducted for this research. The simulations conducted can be divided into two major objectives. The first objective is to confirm that the modelling of the individual behaviours in the virtual environment have some kind of agreement with the real world. The second objective is to show the effectiveness and usefulness of the simulation approach.

The first objective is mostly accomplished through the simulation of the software validation. The results show that the simulation is able to represent some of the individual behaviours observed in the real world. For example, the simulation succeeded in visualising the slower movement in opposite direction compared to same direction movement that was affected by avoiding behaviour. The simulation also reflected on the slower movement caused by a higher density crowd.

Although the effect of visual perception and personal space parameters in the virtual environment is considered slightly different than in the real world, the simulation results indicated that both parameters affected human movement and behaviour. Lastly, the simulation confirmed that the involvement of older people in a crowd can affect human movement and behaviour. There is a possibility of humans performing Competitive and Queuing behaviour depending on the space available in the crowd.

The second objective was accomplished through the simulation of the case studies consisting of a multi-mode transportation system, bottleneck and non-bottleneck layouts with the emergency situation in empty building design. The results indicated that the simulation is beneficial in visualising different possible layouts before real construction or modification takes place. The method is efficient in saving time and cost while providing solutions that can produce more ideas

innovation for the development of building design. In addition, the simulation is useful for the crowd safety application such as traffic control and emergency situations. By applying the simulation method provided in these research different types of situation can be explored and real dangerous situations are not faced. The simulation is also not limited to large areas such as the multi-mode transportation system but also could be applied in smaller areas such as office design in bottleneck and non-bottleneck layouts.

In the next chapter a conclusion and future work of the research is provided.

Chapter 8: Conclusions and Future Research

8.1 Conclusions

The overall aim of this research was to understand aspects of human movement and behaviour in the real world and to build this knowledge into a prototype ‘toolkit’ or computer program that was able to simulate human movement and behaviour in crowded areas. The ‘Design for All’ philosophy was an important context of the work and so older people and those with disabilities were of particular interest in the data collection and simulation. In this section, the research is concluded by detailing the contributions, advantages and limitations of the work.

8.1.1 Contributions

The contributions made by this research can be summarised as;

1. The development of conceptual behaviours (together with observational supporting software and observational database) that make a useful contribution towards understanding individual human movement and behaviour in the real world. The method provided a new step-by-step guidance to assist the observational process as shown in Chapter 4.
2. Video observation based on conceptual behaviour that was applied in this research as shown in Chapter 5 confirmed that the developed method contributes the analysis of nearly 19,000 individual movements and behaviours at a multi-mode transportation system. The

detailed analysis with some unpredictable or natural movements and behaviours observed contributes to new understanding of humans within crowded areas.

3. Gaming software based on the object-oriented concept is capable of simulating human movement and behaviour in a virtual environment with some modification. The development of models to transfer the understanding (or knowledge) of human movement and behaviour from the real world to the virtual environment as discussed in Chapter 6 provided a new method of simulation.
4. The case studies indicated that the simulation has some agreement with movement and behaviour in the real world and could be an important tool to aid the designing of public spaces. Chapter 7 shows that the simulation using gaming software provided new insight of simulation and the application was not only limited to entertainment purposes whilst ‘serving the community’ through examples of real world problem solving.

8.1.2 Advantages

The research work has provided a step-by-step guidance in order to understand human movement and behaviour in the real world through the development of conceptual behaviour (together with observational supporting software and observational database). The method can be applied with any recorded video (from any areas) and is not limited to the multi-mode transportation system. The research work also provided a method to transfer the understanding of human movement and behaviour from real world to the virtual environment for simulation purposes. The method that is based on the object-oriented concept can be expanded with different characteristics of subjects.

The simulation conducted using the DarkBASIC Professional (DBPro) provided a new insight towards the application of gaming software for crowd related research. With the simple

BASIC computing language, the software is able to provide more realism in the simulation with unique commands to display graphics, control image and ability to create and import 2D and 3D images. The software also has artificial intelligence commands called DarkAI to support the movement of virtual entities. DBPro also has an efficient supporting system including a website, newsletter and forum to help in solving problems related to the coding. In addition, the simulation can be developed at low cost while all the simulations or games created using the language are licence and royalty free.

8.1.3 Limitations

Although there are a lot of advantages gained from the research work, some limitations were also identified. Firstly, the video observational method based on conceptual behaviour can be considered as a tedious method. Although the method has advantages in observing some unpredictable or natural movements and behaviours, the manual observation technique required a lot of time for the analysis process. Therefore, other technique could be considered to support the proposed method.

Secondly, the number of entities in the current crowd simulation is limited to 90. Since the number of humans (in a crowd) in the real world can be considerably more than this, a different simulation technique with more processing power could be applied for the simulation. This is to ensure the simulation reflects the real world situation and can be applied in many areas of research. Besides, different types of virtual entities can be considered and not limited to the adult and older subjects.

Lastly, the validation process at the moment is only focused on finding the similarity between the simulation results with the video taken at the multi-mode transportation system. The

simulation is able to demonstrate the similarity of movement and behaviour between the humans in the real world and virtual entities in the virtual environment. However, there is a need to further verify and validate the software. For example, what is the real movement and behaviour of human in crowd when there is a layout changes within the area? Although the software is able to simulate the situation, there is need to conduct some basic research to support the research work.

8.2 Future Research

This research was conducted with the aim of developing a toolkit or computer program that is able to simulate human movement and behaviour in crowded areas. The computer program was developed with adult and older subjects and relevant simulations were conducted covering the software validation and case studies. Based on the contributions, advantages and limitations of the research work, the future research is suggested.

Firstly, since the manual observational method can be considered as a tedious method other methods such as image processing techniques or automatic observational software could be applied. The method could support to acquire important data regarding human movement and behaviour in shorter time. Also, quantitative methods such as questionnaires and structured interviews could be applied to access people in order to have direct communication with the subject and to confirm the behaviour performed. The quantitative methods also could be applied to understand other psychological, sociological and physiological factors that affect human movement and behaviour within the crowd.

Secondly, in order to simulate real movement and behaviour of humans in crowd at different situations and areas, the number of entities should be increased up to hundred or a thousand. Besides, there is need to consider various subjects including those with disabilities to reflect on the AUNT-SUE project. The selected area for the simulation (the Stesen Sentral) is considered

adequate to acquire important movement and behaviour from people. However, the number of older people and those with disabilities observed at the observation area is considered limited for the analysis. Therefore, in order to understand the real movement and behaviour of various subjects from the real world, different places could be considered as the observation area including for example care homes for older people and those with disabilities.

Finally, an experiment using a laboratory setup could be developed in order to validate the simulation results especially the effect of different layouts on human movement and behaviour in crowds. For example, the experimental work could be used to confirm that any modification or improvement that succeeds in the virtual environment has a similar result in the real world so that better simulations can be conducted in order to reflect on the real world application.

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Appendix A (List of Publications)

A.1 Journal

1. **S. Mohamaddan** and K. Case, “*An ‘Inclusive Design’ Approach to Human Behaviour Modelling and Simulation*”, International Journal of Design and Innovation (IJDI), Universiti Malaysia Sarawak (UNIMAS), 2013 (Submitted)

A.2 International Conferences

1. K. Case, M. Freebody, **S. Mohamaddan** and S.T. Syed Shazali, “*Human Behaviour Modelling Using Gaming Software*”, International Conference on Manufacturing Research, Glasgow, September 2011
2. **S. Mohamaddan**, K. Case and C. W. Loon, “*Human Behaviour Simulation Using Gaming Software Based on Video Observation Analysis*”, International Conference In Humanities, Social Sciences and Technology, Cardiff, July 2012
3. **S. Mohamaddan** and K. Case, “*Agent-Based Modelling and Simulation Through Video Observation Analysis*”, International FLINS Conference on Uncertainty Modelling in Knowledge Engineering and Decision Making, Istanbul, August 2012
4. **S. Mohamaddan** and K. Case, “*Towards Understanding of Human Behaviour in Crowded Spaces Using Video Observation Analysis*”, International Conference on Manufacturing Research, Birmingham, September 2012
5. **S. Mohamaddan** and K. Case, “*Simulation of Human Movement and Behaviour in Crowded Spaces Using Gaming Software*”, International Conference on Manufacturing Research, Cranfield, September 2013

Appendix B (Simulation Source Code)

B.1 Free Direction Movement

```
Rem ***** Main Source File *****
```

```
Rem *** Display ***  
Set Display Mode 1366, 768, 32  
Sync On: Sync Rate 0: Autocam Off  
Set Text Font "Arial Black": Set Text Size 20  
Ink RGB (0, 255, 0), 0
```

```
Set Window On  
Set Window Position 0, 0
```

```
AI Start  
AI Set Radius 8
```

```
Entities = 30  
EntitiesOn = 0
```

```
Rem *** Camera Position ***  
CameraX = 450  
CameraY = 450  
CameraZ = 0
```

```
Position Camera CameraX, CameraY, CameraZ  
Point Camera 0, 0, 0
```

```
Rem *** Create Light ***  
Make Light 1  
Sync  
Position Light 1, 300, 200, 0  
Sync  
Set Ambient Light 30  
Rem *** Make Floor ***  
Make Object Box 100, 600, 1, 600  
Position Object 100, 0, -1, 0  
Color Object 100, RGB (125,125,125)
```

```
Rem *** Make Boundary Obstacles ***  
AI Start New Obstacle
```

```
AI Add Obstacle Vertex -300, -365  
AI Add Obstacle Vertex 300, -365  
AI Add Obstacle Vertex 300, 365  
AI Add Obstacle Vertex -300, 365
```

AI End New Obstacle 0, 1

AI Complete Obstacles

Rem *** Make Movement Path ***

AI Make Path 1

AI Path Add Point 1, 200, -200

AI Path Add Point 1, -200, 200

AI Path Add Point 1, 200, 200

AI Make Path 2

AI Path Add Point 2, -275, 275

AI Path Add Point 2, 275, -275

AI Path Add Point 2, -275, -275

AI Path Add Point 2, 275, 275

AI Make Path 3

AI Path Add Point 3, -150, 150

AI Path Add Point 3, 150, -150

Rem *** Entities Detail ***

For I = 1 to Entities

Load Object "Media/HumanAni.x", I

Loop Object I

Position Object I, RND (600) -300, -1, -(RND (40) + 325)

AI Add Enemy I

AI Set Entity Speed I, 48

AI Entity Assign Patrol Path I, RND (2) + 1

AI Set Entity View Arc I, 70, 90

AI Set Entity View Range I, 20

NEXT I

Rem *** Handle Debugging Output ***

DO

IF keystate(2)=1 and ptimer<timer()

ptimer = timer()+300

pMode = 1-pMode

IF (pMode=0) then AI Debug Hide Paths else AI Debug Show Paths 2.5

ENDIF

IF keystate(3)=1 and btimer<timer()

btimer = timer()+300

bMode = 1-bMode

IF (bMode=0) then AI Debug Hide Obstacle Bounds 0 else AI Debug Show Obstacle Bounds
0, 2.5

ENDIF

IF keystate(4)=1 and vtimer<timer()

```
vtimer = timer()+300  
vMode = 1-vMode
```

```
IF ( vMode=0 ) then AI Debug Hide View Arcs else AI Debug Show View Arcs 2.5  
ENDIF
```

```
IF (keystate(59)=1 and flTimer<timer())  
flTimer = timer()+300
```

```
F1Pressed=1-F1Pressed  
ENDIF
```

```
IF (F1Pressed)  
Rem *** Display Info ***  
Set Cursor 0, 0  
Print "Entities Move in Random Path (Free Direction)"  
Print ""  
Print "[1] Toggle Entities Path"  
Print "[2] Toggle Obstacle Bounds"  
Print "[3] Toggle Entities View Arc"  
Print ""  
Print "FPS: "; Screen FPS()
```

```
Else
```

```
Center Text Screen Width (/2, 30,"-- Press F1 For Help --"  
Set Cursor 0, 0  
Print "Entities Move in Random Path (Free Direction)"
```

```
ENDIF
```

```
AI Update  
Sync
```

```
Loop
```

```
Wait Key  
End
```

B.2 Same Direction Movement

Rem ***** Main Source File *****

Rem *** Display ***

Set Display Mode 1366, 768, 32

Sync On: Sync Rate 0: Autocam Off

Set Text Font "Arial": Set Text Size 20

Ink RGB (0, 255, 0), 0

Set Window On

Set Window Position 0, 0

Rem *** Loading Screen ***

Load Bitmap "Media/SDD2.jpg", 1

Copy Bitmap 1, 0, 0, 899, 522, 0, 0, 0, Screen Width(), Screen Height()

Syn : Delete Bitmap 1

Rem *** Entities and Runtime Input ***

Set Cursor 1,300

Input "Please Enter Number of Entities (1-90): ", Entities

While Entities < 1 Or Entities > 90

 Ink RGB (255, 0, 0), 0

 Print "The Entities Must In The Range of 1 to 90"

 Ink RGB (0, 255, 0), 0

 Input "Please Enter Number of Entities (1-90): ", Entities

ENDWHILE

Input "Please Enter Number of Adult: ", AdultAI

While AdultAI < 0 Or AdultAI > Entities

 Ink RGB (255, 0, 0), 0

 Print "The Adult Entities Must In The Range of 1 to ", Entities

 Ink RGB (0, 255, 0), 0

 Input "Please Enter Number of Adult: ", AdultAI

ENDWHILE

OldAI = Entities - AdultAI

Print "The Elderly Entities Are ", OldAI

Input "Please Enter Simulation Running Time in Second(s): ", RunTime

While RunTime < 1

 Ink RGB (255, 0, 0), 0

 Print "The Runtime Must Above 1 Second"

 Ink RGB (0, 255, 0), 0

 Input "Please Enter Simulation Running Time in Second(s): ", RunTime

ENDWHILE

AI Start
AI Set Radius 5

EntitiesOn = 0

Rem *** Camera Position ***
CameraY = 600
Position Camera 1, 600, 0
Point Camera 0, 0, 0

Rem *** Dimension ***
DIM StartTime (Entities)
DIM EndTime (Entities)
DIM TravelTime (Entities)
DIM Categories\$ (Entities)

Rem *** Make Floor ***
Make Object Box 200, 600, 1, 600
Position Object 200, 0, -1, 0
Color Object 200, RGB (125, 125, 125)

Rem *** Make Boundary Obstacles ***
AI Start New Obstacle

AI Add Obstacle Vertex -300, -365
AI Add Obstacle Vertex 300, -365
AI Add Obstacle Vertex 300, 365
AI Add Obstacle Vertex -300, 365

AI End New Obstacle 0, 1
AI Complete Obstacles

Rem *** Database ***
If File Exist ("ANALYSIS OF SAME DIRECTION MOVEMENT.dat")
Delete File "ANALYSIS OF SAME DIRECTION MOVEMENT.dat"
ENDIF

Open to Write 1, "ANALYSIS OF SAME DIRECTION MOVEMENT.dat"
Write String 1, "ANALYSIS OF SAME DIRECTION MOVEMENT IN EMPTY SPACE"
Write String 1, " "
Write String 1, "Travelling Distance for the Entities is 30 Meters"
Write String 1, " "
Write String 1, "ENTITIES ID, TIME TAKEN, CATEGORIES"

Rem *** Create AI ***
For I = 1 to AdultAI
CreateAdultAI (I)
StartTime (I) = Timer ()/1000
Position Object I, RND (600) -300, -1, - (RND (40) + 325)

```

AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)
Loop Object I
Sync
EntitiesOn = EntitiesOn + 1
NEXT I

For I = AdultAI + 1 to Entities
CreateOldAI (I)
StartTime (I) = Timer ()/1000
Position Object I, RND (600) -300, -1, - (RND (40) + 325)
AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)
Loop Object I
Sync
EntitiesOn = EntitiesOn + 1
NEXT I

StartSimulation = Timer ()/1000

Do
Rem *** Handle Debugging Output ***
If Keystate (2) = 1 and ptimer < timer()
    ptimer = timer()+300
    pMode = 1-pMode

    If (pMode = 0) then AI Debug Hide Paths else AI Debug Show Paths 2.5
ENDIF

If Keystate(3) = 1 and vtimer < timer()
    vtimer = timer()+300
    vMode = 1-vMode

    If (vMode = 0) then AI Debug Hide View Arcs else AI Debug Show View Arcs 2.5
ENDIF

If Keystate(4) = 1 and atimer < timer()
    atimer = timer()+300
    aMode = 1-aMode
    If (aMode = 0) then AI Debug Hide Avoidance Angles else AI Debug Show Avoidance
Angles 2.5
ENDIF

If (Keystate(59) = 1 and flTimer < timer())
    flTimer = timer ()+300

    F1Pressed = 1-F1Pressed
ENDIF

TimeNow = Timer ()/1000
CurrentTime = TimeNow - StartSimulation

If (F1Pressed)
    Rem *** Display Info ***

    Set Cursor 0, 0

```



```

Print "Same Direction Movement in Empty Space"
Print " "
Print "Entities Follow Designed Path (Movement Objective) and Avoid Other Entities"
Print " "
Print "Time: ", CurrentTime
Print "No. of Entities on the Space: ", EntitiesOn
Print " "
Print " "
Print "Debug Controls:"
Print "[1] Toggle Entities Paths"
Print "[2] Toggle Entities View Arcs"
Print "[3] Toggle Entities Avoidance Angle"
Print "Camera Controls:"
Print "[PgUp] Zoom Out"
Print "[PgDown] Zoom In"
Print "[Home] Original Position"
Print " "
Print "[Esc] Exit Simulation"
Print " "
Print "FPS: "; Screen FPS()
If Stop = 1
    Print "The Simulation is END"
ENDIF

```

Else

```

Center Text Screen Width (/2,30,"-- Press F1 For Help --"
Set Cursor 0, 0
Print "Same Direction Movement in Empty Space"
Print " "
Print "Time: ", CurrentTime
Print "No. of Entities on the Space: ", EntitiesOn
If Stop = 1
    Print "The Simulation is END"
ENDIF
ENDIF

```

```

Rem *** [PgUp] - Zoom Out ***
If Keystate(201) = 1
    CameraY = CameraY + 10
    If CameraY > 1000 then CameraY = 1000
    Position Camera 1, CameraY, 0
    Point Camera 0, 0, 0
ENDIF

```

```

Rem *** [PgDown] - Zoom In ***
If Keystate (209) = 1
    CameraY = CameraY - 10
    If CameraY < 300 then CameraY = 300
    Position Camera 1, CameraY, 0
    Point Camera 0, 0, 0
ENDIF

```

Rem *** [Home] - Original Position ***

```
If Keystate (199) = 1
  Position Camera 1, 600, 0
  Point Camera 0, 0, 0
ENDIF
```

Rem *** Calculation Time and Kill AI ***

For I = 1 to Entities

```
If AI Get Entity Z (I) > (300)
  EndTime (I) = Timer ()/1000
  TravelTime (I) = EndTime(I) - StartTime(I)
  DataLine$ = Str$(I) + " " + Str$(TravelTime(I)) + " " + Categories$(I)
  Write String 1, DataLine$
  Hide Object I
  AI Kill Entity I
  Delete Object I
  EntitiesOn = EntitiesOn - 1
ENDIF
```

If AI Entity Exist (I) = 0

If Categories\$(I) = "Adult"

CreateAdultAI (I)

Else

CreateOldAI (I)

ENDIF

StartTime (I) = Timer ()/1000

Position Object I, RND (600) - 300, -1, - (RND (40) + 325)

AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)

Loop Object I

Sync

EntitiesOn = EntitiesOn + 1

ENDIF

NEXT I

Rem *** Running Time End ***

If RunTime = CurrentTime

Stop = 1

ENDIF

If Stop = 1

For I = 1 to Entities

AI Set Entity Speed I, 0

Stop Object I

NEXT I

ENDIF

AI Update

Sync

LOOP

Wait Key

End

Rem *** Function ***

FUNCTION CreateAdultAI (I)

Load Object "Media/HumanAni.x", I

AI Add Enemy I

AI Set Entity Speed I, 48

AI Set Entity View Arc I, 70, 90

AI Set Entity View Range I, 20

Categories\$(I) = "Adult"

ENDFUNCTION

FUNCTION CreateOldAI (I)

Load Object "Media/OldAni.x", I

AI Add Enemy I

AI Set Entity Speed I, 32

AI Set Entity View Arc I, 80, 100

AI Set Entity View Range I, 10

Categories\$(I) = "Old"

ENDFUNCTION

B.3 Opposite Direction Movement

Rem ***** Main Source File *****

Rem *** Display ***
Set Display Mode 1366, 768, 32
Sync On: Sync Rate 0: Autocam Off
Set Text Font "Arial": Set Text Size 20
Ink RGB (0, 255, 0), 0

Set Window On
Set Window Position 0, 0

Rem *** Loading Screen ***
Load Bitmap "Media/OD1.jpg", 1
Copy Bitmap 1, 0, 0, 899, 522, 0, 0, 0, Screen Width (), Screen Height ()
Sync: Delete Bitmap 1

Rem *** Entities and Runtime Input ***
Set Cursor 1, 300
Input "Please Enter Number of Entities (1-90): ", Entities
While Entities < 1 Or Entities > 90
 Ink RGB (255, 0, 0), 0
 Print "The Entities Must In The Range of 1 to 90"
 Ink RGB (0, 255, 0), 0
 Input "Please Enter Number of Entities (1-90): ", Entities
ENDWHILE

Input "Please Enter Number of Adult: ", AdultAI
While AdultAI < 0 Or AdultAI > Entities
 Ink RGB (255, 0, 0), 0
 Print "The Adult Entities Must In The Range of 1 to ", Entities
 Ink RGB (0, 255, 0), 0
 Input "Please Enter Number of Adult: ", AdultAI
ENDWHILE

OldAI = Entities - AdultAI
Print "The Elderly Entities Are ", OldAI

Input "Please Enter Simulation Running Time in Second(s): ", RunTime
While RunTime < 1
 Ink RGB (255, 0, 0), 0
 Print "The Runtime Must Above 1 Second"
 Ink RGB (0, 255, 0), 0
 Input "Please Enter Simulation Running Time in Second(s): ", RunTime
ENDWHILE

AI Start
AI Set Radius 10

EntitiesOn = 0

Rem *** Camera Position ***
CameraY = 600
Position Camera 1, 600, 0
Point Camera 0, 0, 0

Rem *** Dimension ***
DIM StartTime (Entities)
DIM EndTime (Entities)
DIM TravelTime (Entities)
DIM StartPoint (Entities)
DIM Categories\$ (Entities)
Rem *** Make Floor ***
Make Object Box 200, 600, 1, 600
Position Object 200, 0, -1, 0
Color Object 200, RGB (125, 125, 125)

Rem *** Make Boundary Obstacles ***
AI Start New Obstacle

AI Add Obstacle Vertex -300, -365
AI Add Obstacle Vertex 300, -365
AI Add Obstacle Vertex 300, 365
AI Add Obstacle Vertex -300, 365

AI End New Obstacle 0, 1
AI Complete Obstacles

Rem *** Database ***
If File Exist ("ANALYSIS OF OPPOSITE DIRECTION MOVEMENT.dat")
 Delete File "ANALYSIS OF OPPOSITE DIRECTION MOVEMENT.dat"
ENDIF

Open to Write 1, "ANALYSIS OF OPPOSITE DIRECTION MOVEMENT.dat"
Write String 1, "ANALYSIS OF OOPOSITE DIRECTION MOVEMENT IN EMPTY SPACE"
Write String 1, " "
Write String 1, "Travelling Distance for the Entities is 30 Meters"
Write String 1, " "
Write String 1, "ENTITIES ID, TIME TAKEN, CATEGORIES"

Rem *** Create AI ***
For I = 1 to AdultAI
 AdultPoint (I, 600, 100, 600)
 EntitiesOn = EntitiesOn + 1
NEXT I

```

For I = AdultAI + 1 to Entities
  ElderlyPoint (I, 600, 100, 600)
  EntitiesOn = EntitiesOn + 1
NEXT I

StartSimulation = Timer ()/1000

Do
  Rem *** Handle Debugging Output ***
  If Keystate (2) = 1 and ptimer < timer()
    ptimer = timer()+300
    pMode = 1-pMode

    If (pMode = 0) then AI Debug Hide Paths else AI Debug Show Paths 2.5
  ENDIF

  If Keystate (3) = 1 and vtimer < timer()
    vtimer = timer()+300
    vMode = 1-vMode

    If (vMode = 0) then AI Debug Hide View Arcs else AI Debug Show View Arcs 2.5
  ENDIF

  If Keystate (4) = 1 and atimer < timer()
    atimer = timer()+300
    aMode = 1-aMode

    If (aMode = 0) then AI Debug Hide Avoidance Angles else AI Debug Show Avoidance
    Angles 2.5
  ENDIF

  If (Keystate (59) = 1 and f1Timer < timer())
    f1Timer = timer()+300

    F1Pressed = 1-F1Pressed
  ENDIF
  TimeNow = Timer ()/1000
  CurrentTime = TimeNow - StartSimulation

  If (F1Pressed)
    Rem *** Display Info ***

    Set Cursor 0, 0
    Print "Oppsite Direction Movement in Empty Space"
    Print " "
    Print "Entities Follow Designed Path (Movement Objective) and Avoid Other Entities"
    Print " "
    Print "Red Entities Move From Left to Right"
    Print "Blue Entities Move From Right to Left"
    Print " "
    Print "Time: ", CurrentTime
    Print "No. of Entities on the Space: ", EntitiesOn
    Print " "

```

```

Print " "
Print "Debug Controls:"
Print "[1] Toggle Entities Paths"
Print "[2] Toggle Entities View Arcs"
Print "[3] Toggle Entities Avoidance Angle"
Print "Camera Controls:"
Print "[PgUp] Zoom Out"
Print "[PgDown] Zoom In"
Print "[Home] Original Position"
Print " "
Print "[Esc] Exit Simulation"
Print " "
Print "FPS: "; Screen FPS()
If Stop = 1
    Print "The Simulation is END"
ENDIF

```

Else

```

Center Text Screen Width (/2, 30, "-- Press F1 For Help --"
Set Cursor 0, 0
Print "Opposite Direction Movement in Empty Space"
Print " "
Print "Time: ", CurrentTime
Print "No. of Entities on the Space: ", EntitiesOn
If Stop = 1
    Print "The Simulation is END"
ENDIF
ENDIF

```

```

Rem *** [PgUp] - Zoom Out ***
If Keystate (201) = 1
    CameraY = CameraY + 10
    If CameraY > 1000 then CameraY = 1000
    Position Camera 1, CameraY, 0
    Point Camera 0, 0, 0
ENDIF

```

```

Rem *** [PgDown] - Zoom In ***
If Keystate (209) = 1
    CameraY = CameraY - 10
    If CameraY < 300 then CameraY = 300
    Position Camera 1, CameraY, 0
    Point Camera 0, 0, 0
ENDIF

```

```

Rem *** [Home] - Original Position ***
If Keystate (199) = 1
    Position Camera 1, 600, 0
    Point Camera 0, 0, 0
ENDIF

```

```
Rem *** Calculation Time and Kill AI ***
For I = 1 to Entities
```

```
  If StartPoint (I) = 1
    If AI Get Entity Z (I) > (300)
      EndTime (I) = Timer ()/1000
      TravelTime (I) = EndTime(I) - StartTime(I)
      DataLine$ = Str$(I) + "          " + Str$(TravelTime(I)) + "          " + Categories$(I)
      Write String 1, DataLine$
      Hide Object I
      AI Kill Entity I
      Delete Object I
      EntitiesOn = EntitiesOn - 1
    ENDIF
  ENDIF
```

```
  If StartPoint (I) = 2
    If AI Get Entity Z (I) < (-300)
      EndTime(I) = Timer()/1000
      TravelTime(I) = EndTime(I) - StartTime(I)
      DataLine$ = Str$(I) + "          " + Str$(TravelTime(I)) + "          " + Categories$(I)
      Write String 1, DataLine$
      Hide Object I
      AI Kill Entity I
      Delete Object I
      EntitiesOn = EntitiesOn - 1
    ENDIF
  ENDIF
```

```
  If AI Entity Exist (I) = 0
    If Categories$(I) = "Adult"
      AdultPoint (I, 600, 100, 600)
    Else
      ElderlyPoint (I, 600, 100, 600)
    ENDIF
    EntitiesOn = EntitiesOn + 1
  ENDIF
```

```
NEXT I
```

```
Rem *** Running Time End ***
```

```
If RunTime = CurrentTime
  Stop = 1
ENDIF
```

```
If Stop = 1
  For I = 1 to Entities
    AI Set Entity Speed I, 0
    Stop Object I
  NEXT I
ENDIF
```


AI Update
Sync

LOOP

Wait Key
End

Rem *** Function ***

FUNCTION AdultPoint (I, Width#, Height#, Depth#)

StartPoint (I) = RND (1) + 1

If StartPoint (I) = 1

Load Object "Media/HumanAni.x", I

AI Add Enemy I

AI Set Entity Speed I, 24

AI Set Entity View Arc I, 160, 210

AI Set Entity View Range I, 40

Color Object I, RGB (255, 0, 0)

StartTime (I) = Timer ()/1000

Position Object I, RND (600) - 300, 10, - (RND (40) + 325)

AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)

Loop Object I

Categories\$(I) = "Adult-L2R"

ENDIF

If StartPoint (I) = 2

Load Object "Media/HumanAni.x", I

AI Add Enemy I

AI Set Entity Speed I, 24

AI Set Entity View Arc I, 160, 210

AI Set Entity View Range I, 40

Color Object I, RGB (0, 0, 255)

StartTime (I) = Timer ()/1000

Position Object I, RND (600) - 300, 10, (RND (40) + 325)

AI Entity Go to Position I, (RND (600) - 300), - (RND (40) + 325)

Loop Object I

Categories\$(I) = "Adult"

ENDIF

Sync

ENDFUNCTION

FUNCTION ElderlyPoint (I, Width#, Height#, Depth#)

StartPoint (I) = RND (1) + 1

If StartPoint (I) = 1

Load Object "Media/OldAni.x", I

AI Add Enemy I

AI Set Entity Speed I, 16

```

AI Set Entity View Arc I, 140, 190
AI Set Entity View Range I, 20
Color Object I, RGB (255, 160, 255)
StartTime (I) = Timer ()/1000
Position Object I, RND (600) - 300, 10, - (RND (40) + 325)
AI Entity Go to Position I, (RND (600) - 300), (RND (40) + 325)
Loop Object I
Categories$(I) = "Old-L2R"
ENDIF

If StartPoint (I) = 2
Load Object "Media/OldAni.x", I
AI Add Enemy I
AI Set Entity Speed I, 16
AI Set Entity View Arc I, 140, 190
AI Set Entity View Range I, 20
Color Object I, RGB (0, 255, 255)
StartTime (I) = Timer ()/1000
Position Object I, RND (600) - 400, 10, (RND (40) + 325)
AI Entity Go to Position I, (RND (800) - 400), - (RND (40) + 325)
Loop Object I
Categories$(I) = "Old"
ENDIF

Sync

ENDFUNCTION

```

B.4 Multi-mode Transportation System Layout

Rem ***** Main Source File *****

Rem *** Display ***

Set Display Mode 1366, 768, 32

Sync On: Sync Rate 0: Autocam Off

Set Text Font "Arial Black": Set Text Size 25

Ink RGB (0, 255, 0), 0

Set Window On

Set Window Position 0, 0

Rem *** Loading Screen ***

Load Bitmap "Media/KLCentral.jpg", 1

Copy Bitmap 1, 0, 0, 899, 522, 0, 0, 0, Screen Width (), Screen Height ()

Sync: Delete Bitmap 1

Rem *** Entities and Runtime Input ***

Set Cursor 1, 300

Input "Please Enter Number of Entities (1-90): ", Entities

While Entities < 1 Or Entities > 90

 Ink RGB (255, 0, 0), 0

 Print "The Entities Must In The Range of 1 to 90"

 Ink RGB (0, 255, 0), 0

 Input "Please Enter Number of Entities (1-90): ", Entities

ENDWHILE

Input "Please Enter Number of Adult: ", AdultAI

While AdultAI < 0 Or AdultAI > Entities

 Ink RGB (255, 0, 0), 0

 Print "The Adult Entities Must In The Range of 1 to ", Entities

 Ink RGB (0, 255, 0), 0

 Input "Please Enter Number of Adult: ", AdultAI

ENDWHILE

OldAI = Entities - AdultAI

Print "The Elderly Entities Are ", OldAI

Input "Please Enter Simulation Running Time in Second(s): ", RunTime

While RunTime < 1

 Ink RGB (255, 0, 0), 0

 Print "The Runtime Must Above 1 Second"

 Ink RGB (0, 255, 0), 0

 Input "Please Enter Simulation Running Time in Second(s): ", RunTime

ENDWHILE

AI Start
AI Set Radius 5

EntitiesOn = 0

Rem *** Camera Position ***
CameraX = 450
CameraY = 450
CameraZ = 0

Position Camera CameraX, CameraY, CameraZ
Point Camera 0, 0, 0

Rem *** Create Light ***
Make Light 1
Sync
Position Light 1, 300, 200, 0
Set Ambient Light 30

Rem *** Dimension ***
DIM StartTime (Entities)
DIM EndTime (Entities)
DIM TravelTime (Entities)
DIM StartPoint (Entities)
DIM Categories\$ (Entities)

Rem *** Make Floor ***
Make Object Box 200, 600, 1, 600
Position Object 200, 0, -1, 0
Color Object 200, RGB (125, 125, 125)

Rem *** Make Layout Design ***
LOut1 = 201
LOut2 = 202
LOut3 = 203
LOut4 = 204
LOut5 = 205
LOut6 = 206
LOut7 = 207
LOut8 = 208
LOut9 = 209
LOut10 = 210
LOut11 = 211
LOut12 = 212
LOut13 = 213

Rem *** Ticket Machine ***
Make Object Box LOut1, 30, 70, 30

Position Object LOut1, -275, 0, 100
Color Object LOut1, RGB (0, 0, 255)

Make Object Box LOut2, 30, 70, 30
Position Object LOut2, -275, 0, 50
Color Object LOut2, RGB (0, 0, 255)

Make Object Box LOut3, 30, 70, 30
Position Object LOut3, -275, 0, 0
Color Object LOut3, RGB (0, 0, 255)

Rem *** Stall at the Middle ***
Make Object Box LOut4, 60, 50, 300
Position Object LOut4, -70, 0, 0
Color Object LOut4, RGB (255, 0, 0)

Make Object Box LOut5, 60, 50, 300
Position Object LOut5, 70, 0, 0
Color Object LOut5, RGB (255, 0, 0)

Rem *** Information Center ***
Make Object Sphere LOut6, 50
Position Object LOut6, 0, 0, -220
Color Object LOut6, RGB (255, 255, 0)

Rem *** Stall at Side ***
Make Object Box LOut7, 50, 50, 100
Position Object LOut7, 200, 0, 100
Color Object LOut7, RGB (255, 255, 0)

Make Object Box LOut8, 50, 50, 100
Position Object LOut8, 200, 0, -100
Color Object LOut8, RGB (255, 255, 0)

Rem *** Screen and Sign Board ***
Make Object Box LOut9,200,100,2
Position Object LOut9,0,100,370
Color Object LOut9,RGB(255,255,255)

Make Object Box LOut10,150,80,2
Position Object LOut10,0,100,370
Color Object LOut10,RGB(0,255,255)

Make Object Box LOut11,2,50,80
Position Object LOut11,-300,50,-200
Color Object LOut11,RGB(0,255,70)

Rem *** Waiting Area ***
Make Object Box LOut12,80,20,5
Position Object LOut12,-250,0,-250

Color Object LOut12,RGB(128,0,0)

Make Object Box LOut13,80,20,5
Position Object LOut13,-250,0,-150
Color Object LOut13,RGB(128,0,0)

AI Add Static Obstacle LOut1
AI Add Static Obstacle LOut2
AI Add Static Obstacle LOut3
AI Add Static Obstacle LOut4
AI Add Static Obstacle LOut5
AI Add Static Obstacle LOut6
AI Add Static Obstacle LOut7
AI Add Static Obstacle LOut8
AI Add Static Obstacle LOut9
AI Add Static Obstacle LOut10
AI Add Static Obstacle LOut11
AI Add Static Obstacle LOut12
AI Add Static Obstacle LOut13

Rem *** Make Boundary Obstacles ***
AI Start New Obstacle

AI Add Obstacle Vertex -300,-365
AI Add Obstacle Vertex 300,-365
AI Add Obstacle Vertex 300,365
AI Add Obstacle Vertex -300,365

AI End New Obstacle 0,1
AI Complete Obstacles

Rem *** Database ***
If File Exist("ANALYSIS OF KL CENTRAL SIMULATION.dat")
 Delete File "ANALYSIS OF KL CENTRAL SIMULATION.dat"
ENDIF

Open to Write 1,"ANALYSIS OF KL CENTRAL SIMULATION.dat"
Write String 1,"ANALYSIS OF KL CENTRAL SIMULATION"
Write String 1," "
Write String 1,"ENTITIES ID, TIME TAKEN, CATEGORIES"

Rem *** Create AI ***
For I = 1 to AdultAI
 AdultPoint(I,600,100,600)
 EntitiesOn = EntitiesOn + 1
NEXT I

For I = AdultAI + 1 to Entities
 ElderlyPoint(I,600,100,600)
 EntitiesOn = EntitiesOn + 1
NEXT I

StartSimulation = Timer()/1000

Do

Rem *** Handle Debugging Output ***

If Keystate(2) = 1 and ptimer < timer()

ptimer = timer()+300

pMode = 1-pMode

If (pMode = 0) then AI Debug Hide Paths else AI Debug Show Paths 2.5
ENDIF

If Keystate(3) = 1 and vtimer < timer()

vtimer = timer()+300

vMode = 1-vMode

If (vMode = 0) then AI Debug Hide View Arcs else AI Debug Show View Arcs 2.5
ENDIF

If Keystate(4) = 1 and atimer < timer()

atimer = timer()+300

aMode = 1-aMode

If (aMode = 0) then AI Debug Hide Avoidance Angles else AI Debug Show Avoidance
Angles 2.5
ENDIF

If Keystate(5) = 1 and btimer < timer()

btimer = timer()+300

bMode = 1-bMode

If (bMode = 0) then AI Debug Hide Obstacle Bounds 0 else AI Debug Show Obstacle Bounds
0,2.5
ENDIF

If (Keystate(59) = 1 and f1Timer < timer())

f1Timer = timer()+300

F1Pressed = 1-F1Pressed

ENDIF

TimeNow = Timer()/1000

CurrentTime = TimeNow - StartSimulation

If (F1Pressed)

Rem *** Display Info ***

Set Cursor 0,0

Print "KL CENTRAL LAYOUT SIMULATION"

Print " "

Print "Time: ",CurrentTime

Print "No. of Entities on the Space: ",EntitiesOn

Print " "

Print "Debug Controls:"

Print "[1] Toggle Entities Paths"

```

Print "[2] Toggle Entities View Arcs"
Print "[3] Toggle Entities Avoidance Angle"
Print "[4] Toggle Obstacle Bounds"
Print " "
Print "Camera Controls:"
Print "[PgUp] Zoom Out"
Print "[PgDown] Zoom In"
Print "[Home] Original Position"
Print " "
Print "[Esc] Exit Simulation"
Print " "
Print "FPS: ";Screen FPS()
If Stop = 1
  Print "The Simulation is END"
ENDIF

```

Else

```

Center Text Screen Width()/2,30,"-- Press F1 For Help --"
Set Cursor 0,0
Print "KL CENTRAL LAYOUT SIMULATION"
Print " "
Print "Time: ",CurrentTime
Print "No. of Entities on the Space: ",EntitiesOn
If Stop = 1
  Print "The Simulation is END"
ENDIF
ENDIF

```

```

Rem *** [PgUp] - Zoom Out ***
If Keystate(201) = 1
  CameraY = CameraY + 5
  If CameraY > 1000 then CameraY = 1000
  Position Camera 1,CameraY,0
  Point Camera 0,0,0
ENDIF

```

```

Rem *** [PgDown] - Zoom In ***
If Keystate(209) = 1
  CameraY = CameraY - 5
  If CameraY < 300 then CameraY = 300
  Position Camera 1,CameraY,0
  Point Camera 0,0,0
ENDIF

```

```

Rem *** [Home] - Original Position ***
If Keystate(199) = 1
  Position Camera CameraX,CameraY,CameraZ
  Point Camera 0,0,0
ENDIF

```



```
Rem *** Calculation Time and Kill AI ***  
For I = 1 to Entities
```

```
  If StartPoint(I) = 1  
    If AI Get Entity Z(I) > (300)  
      EndTime(I) = Timer()/1000  
      TravelTime(I) = EndTime(I) - StartTime(I)  
      DataLine$ = Str$(I) + "      " + Str$(TravelTime(I)) + "      " + Categories$(I)  
      Write String 1,DataLine$  
      Hide Object I  
      AI Kill Entity I  
      Delete Object I  
      EntitiesOn = EntitiesOn - 1  
    ENDIF  
  ENDIF
```

```
  If StartPoint(I) = 2  
    If AI Get Entity Z(I) < (-300)  
      EndTime(I) = Timer()/1000  
      TravelTime(I) = EndTime(I) - StartTime(I)  
      DataLine$ = Str$(I) + "      " + Str$(TravelTime(I)) + "      " + Categories$(I)  
      Write String 1,DataLine$  
      Hide Object I  
      AI Kill Entity I  
      Delete Object I  
      EntitiesOn = EntitiesOn - 1  
    ENDIF  
  ENDIF
```

```
  If AI Entity Exist(I) = 0  
    If Categories$(I) = "Adult"  
      AdultPoint(I,600,100,600)  
    Else  
      ElderlyPoint(I,600,100,600)  
    ENDIF  
    EntitiesOn = EntitiesOn + 1  
  ENDIF
```

```
NEXT I
```

```
Rem *** Running Time End ***
```

```
If RunTime = CurrentTime  
  Stop = 1  
ENDIF
```

```
If Stop = 1  
  For I = 1 to Entities  
    AI Set Entity Speed I,0  
    Stop Object I  
  NEXT I  
ENDIF
```

AI Update
Sync

LOOP

Wait Key
End

Rem *** Function ***

FUNCTION AdultPoint(I,Width#,Height#,Depth#)

StartPoint(I) = RND(1)+1

If StartPoint(I) = 1

Load Object "Media/HumanAni.x",I

AI Add Enemy I

AI Set Entity Speed I,24

AI Set Entity View Arc I,160,210

AI Set Entity View Range I,40

Color Object I,RGB(255,0,0)

StartTime(I) = Timer()/1000

Position Object I,RND(600)-300,10,-(RND(40)+325)

AI Entity Go to Position I,(RND(600)-300),(RND(40)+325)

Loop Object I

Categories\$(I) = "Adult-L2R"

ENDIF

If StartPoint(I) = 2

Load Object "Media/HumanAni.x",I

AI Add Enemy I

AI Set Entity Speed I,24

AI Set Entity View Arc I,160,210

AI Set Entity View Range I,40

Color Object I,RGB(0,0,255)

StartTime(I) = Timer()/1000

Position Object I,RND(600)-300,10,(RND(40)+325)

AI Entity Go to Position I,(RND(600)-300),-(RND(40)+325)

Loop Object I

Categories\$(I) = "Adult"

ENDIF

Sync

ENDFUNCTION

FUNCTION ElderlyPoint(I,Width#,Height#,Depth#)

StartPoint(I) = RND(1)+1

If StartPoint(I) = 1

Load Object "Media/OldAni.x",I

AI Add Enemy I

AI Set Entity Speed I,16

```
AI Set Entity View Arc I,140,190
AI Set Entity View Range I,20
Color Object I,RGB(255,160,255)
StartTime(I) = Timer()/1000
Position Object I,RND(600)-300,10,-(RND(40)+325)
AI Entity Go to Position I,(RND(600)-300),(RND(40)+325)
Loop Object I
Categories$(I) = "Old-L2R"
ENDIF
```

```
If StartPoint(I) = 2
Load Object "Media/OldAni.x",I
AI Add Enemy I
AI Set Entity Speed I,16
AI Set Entity View Arc I,140,190
AI Set Entity View Range I,20
Color Object I,RGB(0,255,255)
StartTime(I) = Timer()/1000
Position Object I,RND(600)-300,10,(RND(40)+325)
AI Entity Go to Position I,(RND(800)-400),-(RND(40)+325)
Loop Object I
Categories$(I) = "Old"
ENDIF
```

Sync

```
ENDFUNCTION
```

B.5 Bottleneck Layout

Rem ***** Main Source File *****

Rem *** Display ***
Set Display Mode 1366,768,32
Sync On : Sync Rate 0 : Autocam Off
Set Text Font "Arial Black" : Set Text Size 20
Ink RGB(0,0,0),0

Set Window On
Set Window Position 0,0

AI Start
AI Set Radius 5

Rem *** Variables ***
Entities = 90
EntitiesOn = 0
NoAI = 0
StageAI = 0
Destination = 0
DestinationOn = 0
TimeAI = 0

Rem *** Dimension ***
DIM StartTime(Entities)
DIM EndTime(Entities)
DIM TravelTime(Entities)
DIM x(Entities)
DIM z(Entities)
DIM Categories\$(Entities)

Rem *** Camera Position ***
CameraX = 0
CameraY = 800
CameraZ = -1
Position Camera CameraX,CameraY,CameraZ
Point Camera 0,0,0

Rem *** Create Light ***
Make Light 1
Sync
Position Light 1,0,150,0
Sync
Set Ambient Light 30

```
Rem *** Make Floor ***
Make Object Box 200,2500,1,1800
Position Object 200,0,-1,0
Color Object 200,RGB(125,125,125)
Set Object Collision Off 200
```

```
Rem *** Load Bottleneck Layout ***
Load Object "Media/building1.x",201
AI Add Obstacle From Level 201,20,20,20
Position Object 201,0,-1,0
Set Object Collision Off 201
```

```
Rem *** Make Boundary Obstacles ***
AI Start New Obstacle
```

```
AI Add Obstacle Vertex -1000,-1000
AI Add Obstacle Vertex 1000,-1000
AI Add Obstacle Vertex 1000,1000
AI Add Obstacle Vertex -1000,1000
AI End New Obstacle 0,1
```

```
AI Complete Obstacles
```

```
Rem *** Database ***
If File Exist("ANALYSIS OF HUMAN MOVEMENT IN BOTTLENECK LAYOUT.dat")
    Delete File "ANALYSIS OF HUMAN MOVEMENT IN BOTTLENECK LAYOUT.dat"
ENDIF
```

```
Open to Write 1,"ANALYSIS OF HUMAN MOVEMENT IN BOTTLENECK LAYOUT.dat"
Write String 1,"ANALYSIS OF HUMAN MOVEMENT IN BOTTLENECK LAYOUT"
Write String 1," "
Write String 1,"ENTITIES ID, TIME TAKEN, CATEGORIES"
```

```
Rem *** Make Mouse Marker ***
Make Object Sphere 202,2
Set Object Collision Off 202
Hide Object 202
```

```
Rem *** Make Destination Marker ***
Make Object Sphere 203,20
Color Object 203,RGB(255,0,0)
Set Object Collision Off 203
Hide Object 203
```

```
Do
    Rem *** Position Mouse Marker ***
    pick screen mousex(),mousey(),1000
    vx# = get pick vector x()
    vy# = get pick vector y()
```

```
vz# = get pick vector z()
dy# = -camera position y()/vy#
vx# = vx#*dy# + camera position x()
vz# = vz#*dy# + camera position z()
position object 202,vx#,1,vz#
```

```
Rem *** Position AI ***
If EntitiesOn <= 89
```

```
  If Mouseclick() = 1
    EntitiesOn = EntitiesOn + 1
    NoAI = NoAI + 1
    StageAI = StageAI + 1
    TimeAI = TimeAI + 1
```

```
  Load Object "Media/HumanAni.x",NoAI
  Position Object NoAI,Object Position x(202),-1,Object Position z(202)
  AI Add Enemy NoAI
  AI Set Entity Speed NoAI,0
  AI Set Entity View Arc NoAI,160,210
  AI Set Entity View Range NoAI,20
  Categories$(NoAI) = "Adult"
```

```
  XPosition = Object Position x(202)
  ZPosition = Object Position z(202)
  While Object Collision(NoAI,0)
    RandomX = RND(2)-1
    RandomZ = RND(2)-1
    XPosition = XPosition + RandomX
    ZPosition = ZPosition + RandomZ
    Position Object NoAI,XPosition,-1,ZPosition
  ENDWHILE
```

```
Wait 200
```

```
ENDIF
```

```
  If Mouseclick() = 2
    EntitiesOn = EntitiesOn + 1
    NoAI = NoAI + 1
    StageAI = StageAI + 1
    TimeAI = TimeAI + 1
```

```
  Load Object "Media/OldAni.x",NoAI
  Position Object NoAI,Object Position x(202),-1,Object Position z(202)
  AI Add Enemy NoAI
  AI Set Entity Speed NoAI,0
  AI Set Entity View Arc NoAI,160,210
  AI Set Entity View Range NoAI,20
  Categories$(NoAI) = "Old"
```

```
  XPosition = Object Position x(202)
  ZPosition = Object Position z(202)
  While Object Collision(NoAI,0)
```

```

    RandomX = RND(2)-1
    RandomZ = RND(2)-1
    XPosition = XPosition + RandomX
    ZPosition = ZPosition + RandomZ
    Position Object NoAI,XPosition,-1,ZPosition
ENDWHILE

Wait 200

ENDIF

If Spacekey() = 1
    Destination = 1
    EntitiesOn = 90
ENDIF

ENDIF

If EntitiesOn = 90
    Destination = 1
ENDIF

Rem *** Set Destination ***
If Destination = 1
    For I = 1 to NoAI
        If Mouseclick() = 1
            Position Object 203,Object Position x(202),-1,Object Position z(202)
            Show Object 203
            DestinationOn = 1
        ENDIF
    NEXT I
ENDIF

Rem *** Start Simulation ***
If DestinationOn = 1
    If Keystate(28) = 1 or Keystate(156)
        Set Object Collision On 203
        Set Object Collision On 201
        EntitiesOn = 91
        For I = 1 to NoAI
            Loop Object I

            If Categories$(I) = "Adult"
                AI Set Entity Speed I,26
            Else
                AI Set Entity Speed I,16
            ENDIF

            StartTime(I) = Timer()/1000
        NEXT
        StartSimulation = Timer()/1000
        Destination = 2
        DestinationOn = 2
    End If
End If

```

```

ENDIF

For I = 1 to NoAI
  AI Entity GO To Position I,Object Position x(203),Object Position z(203)
NEXT I

ENDIF

Rem *** Handle Debugging Output ***
If Keystate(2) = 1 and ptimer < timer()
  ptimer = timer()+300
  pMode = 1-pMode

  If (pMode = 0) then AI Debug Hide Paths else AI Debug Show Paths 2.5
ENDIF

If Keystate(3) = 1 and btimer < timer()
  btimer = timer()+300
  bMode = 1-bMode

  If (bMode = 0) then AI Debug Hide Obstacle Bounds 0 else AI Debug Show Obstacle Bounds
  0,2.5
ENDIF

If Keystate(4) = 1 and vtimer < timer()
  vtimer = timer()+300
  vMode = 1-vMode

  If (vMode = 0) then AI Debug Hide View Arcs else AI Debug Show View Arcs 2.5
ENDIF

If Keystate(5) = 1 and atimer < timer()
  atimer = timer()+300
  aMode = 1-aMode

  If (aMode = 0) then AI Debug Hide Avoidance Angles else AI Debug Show Avoidance Angles
  2.5
ENDIF

If (Keystate(59) = 1 and f1Timer < timer())
  f1Timer = timer()+300

  F1Pressed = 1-F1Pressed
ENDIF

Rem *** Camera Controls ***
If Downkey() = 1
  CameraZ = CameraZ - 10
  If CameraZ < -500 Then CameraZ = -500
  Position Camera CameraX,CameraY,CameraZ
  Point Camera CameraX,0,CameraZ
ENDIF

```



```

If Upkey() = 1
    CameraZ = CameraZ + 10
    If CameraZ > 500 Then CameraZ = 500
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

If RightKey() = 1
    CameraX = CameraX + 10
    If CameraX > 800 Then CameraX = 800
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

If LeftKey() = 1
    CameraX = CameraX - 10
    If CameraX < -800 Then CameraX = -800
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

Rem *** [Page Up] - Zoom Out ***
If Keystate(201) = 1
    CameraY = CameraY + 10
    If CameraY < 1000 Then CameraY = 1000
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

Rem *** [Page Down] - Zoom In ***
If Keystate(209) = 1
    CameraY = CameraY - 10
    If CameraY < 150 Then CameraY = 150
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

Rem *** [Home] - Original Position ***
If Keystate(199) = 1
    CameraX = 0
    CameraY = 800
    CameraZ = -1
    Position Camera CameraX, CameraY, CameraZ
    Point Camera 0, 0, 0
ENDIF

```

```

TimeNow = TIMER()/1000
CurrentTime = TimeNow - StartSimulation

```

```

IF (F1Pressed)
    Rem *** Display Info ***

```

```

Set Cursor 0,0
Print " "
Print "HUMAN MOVEMENT SIMULATION IN BOTTLENECK LAYOUT"
Print " "
Print "No. Of Entities: ",NoAI
Print "No. Of Entities On Stage: ",StageAI
Print " "
Print "Debug Controls:"
Print "[1] Toggle Entity Paths"
Print "[2] Toggle Obstacle Bounds"
Print "[3] Toggle Entity View Arc"
Print "[4] Toggle Entity Avoidance Angles"
Print "Camera Controls:"
Print "  [^] "
Print "[<] [v] [>]"
Print "[PgUp] Zoom Out"
Print "[PgDown] Zoom In"
Print "[Home] Original Position"
Print " "
Print "[ECS] Exit Simulation"
Print " "
Print "FPS: ";Screen FPS()

If Destination = 2
  Print "Time: ",CurrentTime
ENDIF

If TimeAI = -1
  Print "Total Exit Time: ",ExitTime
ENDIF

If EntitiesOn <= 89
  Center Text Screen Width()/2,50,"Please Put Entities Into The Layout. Left Click For Adult,
Right Click For Elderly People"
  Center Text Screen Width()/2,70,"Press SPACEBAR When Enough AI"
ENDIF

If Destination = 1
  Center Text Screen Width()/2,50,"Please Set Destination. Press ENTER to Start Simulation"
ENDIF

If Destination = 2
  Center Text Screen Width()/2,50,"Simulation Started"
ENDIF

If Destination = 3
  Center Text Screen Width()/2,50,"Simulation Ended"
ENDIF

ELSE

Set Cursor 0,0
Print " "
Print "HUMAN MOVEMENT SIMULATION IN BOTTLENECK LAYOUT"
Print " "

```

```

Print "No. Of Entities: ",NoAI
Print "No. Of Entities On Stage: ",StageAI
Print " "

If Destination = 2
  Print "Time: ",CurrentTime
ENDIF

If TimeAI = -1
  Print "Total Exit Time: ",ExitTime
ENDIF

Center Text Screen Width()/2,30,"-- Press F1 For Help --"
If EntitiesOn <= 89
  Center Text Screen Width()/2,50,"Please Put Entities Into The Layout. Left Click For Adult,
Right Click For Elderly People"
  Center Text Screen Width()/2,70,"Press SPACEBAR When Enough AI"
ENDIF

If Destination = 1
  Center Text Screen Width()/2,50,"Please Set Destination. Press ENTER to Start Simulation"
ENDIF

If Destination = 2
  Center Text Screen Width()/2,50,"Simulation Started"
ENDIF

If Destination = 3
  Center Text Screen Width()/2,50,"Simulation Ended"
ENDIF

ENDIF

Rem *** Calculation Time and Kill AI ***
For I = 1 to NoAI
  If Object Hit(203,I)
    EndTime(I) = Timer()/1000
    TravelTime(I) = EndTime(I) - StartTime(I)
    DataLine$ = Str$(I) + " " + Str$(TravelTime(I)) + " " + Categories$(I)
    Write String 1,DataLine$
    AI Kill Entity I
    Delete Object I
    StageAI = StageAI - 1
    TimeAI = TimeAI - 1
  ENDIF

If TimeAI = 0
  EndSimulation = Timer()/1000
  ExitTime = EndSimulation - StartSimulation
  TimeAI = -1
  Write String 1, " "
  Write String 1, "Total Exit Time(in Second) is: " + Str$(ExitTime)
  Destination = 3
ENDIF

```

```
If AI Entity Exist(I) = 0
  Make Object Sphere I,10
  Color Object I,RGB(255,0,0)
  AI Add Enemy I
  AI Set Entity Speed I,0
  Position Object I,3000,-1,0
  AI Entity Go To Position I,3000,0
  Hide Object I
ENDIF
```

```
NEXT I
```

```
  AI Update
  SYNC
```

```
LOOP
```

```
Wait Key
END
```

B.6 Non-bottleneck Layout

Rem ***** Main Source File *****

Rem *** Display ***
Set Display Mode 1366,768,32
Sync On : Sync Rate 0 : Autocam Off
Set Text Font "Arial Black" : Set Text Size 20
Ink RGB(0,0,0),0

Set Window On
Set Window Position 0,0

AI Start
AI Set Radius 10

Rem *** Variables ***
Entities = 90
EntitiesOn = 0
NoAI = 0
StageAI = 0
Destination = 0
DestinationOn = 0
TimeAI = 0

Rem *** Dimension ***
DIM StartTime(Entities)
DIM EndTime(Entities)
DIM TravelTime(Entities)
DIM x(Entities)
DIM z(Entities)
DIM Categories\$(Entities)

Rem *** Camera Position ***
CameraX = 0
CameraY = 800
CameraZ = -1
Position Camera CameraX,CameraY,CameraZ
Point Camera 0,0,0

Rem *** Create Light ***
Make Light 1
Sync
Position Light 1,0,150,0
Sync
Set Ambient Light 30

```
Rem *** Make Floor ***
Make Object Box 200,2500,1,1800
Position Object 200,0,-1,0
Color Object 200,RGB(125,125,125)
Set Object Collision Off 200
```

```
Rem *** Load Bottleneck Layout ***
Load Object "Media/building2.x",201
AI Add Obstacle From Level 201,20,20,20
Position Object 201,0,-1,0
Set Object Collision Off 201
```

```
Rem *** Make Boundary Obstacles ***
AI Start New Obstacle
```

```
AI Add Obstacle Vertex -1000,-1000
AI Add Obstacle Vertex 1000,-1000
AI Add Obstacle Vertex 1000,1000
AI Add Obstacle Vertex -1000,1000
AI End New Obstacle 0,1
```

```
AI Complete Obstacles
```

```
Rem *** Database ***
If File Exist("ANALYSIS OF HUMAN MOVEMENT IN NON-BOTTLENECK LAYOUT.dat")
    Delete File "ANALYSIS OF HUMAN MOVEMENT IN NON-BOTTLENECK LAYOUT.dat"
ENDIF
```

```
Open to Write 1,"ANALYSIS OF HUMAN MOVEMENT IN NON-BOTTLENECK
LAYOUT.dat"
Write String 1,"ANALYSIS OF HUMAN MOVEMENT IN NON-BOTTLENECK LAYOUT"
Write String 1," "
Write String 1,"ENTITIES ID, TIME TAKEN, CATEGORIES"
```

```
Rem *** Make Mouse Marker ***
Make Object Sphere 202,2
Set Object Collision Off 202
Hide Object 202
```

```
Rem *** Make Destination Marker ***
Make Object Sphere 203,20
Color Object 203,RGB(255,0,0)
Set Object Collision Off 203
Hide Object 203
```

```
Do
    Rem *** Position Mouse Marker ***
    pick screen mousex(),mousey(),1000
    vx# = get pick vector x()
```

```

vy# = get pick vector y()
vz# = get pick vector z()
dy# = -camera position y()/vy#
vx# = vx#*dy# + camera position x()
vz# = vz#*dy# + camera position z()
position object 202,vx#,1,vz#

```

```

Rem *** Position AI ***
If EntitiesOn <= 89

```

```

    If Mouseclick() = 1
    EntitiesOn = EntitiesOn + 1
    NoAI = NoAI + 1
    StageAI = StageAI + 1
    TimeAI = TimeAI + 1

```

```

    Load Object "Media/HumanAni.x",NoAI
    Position Object NoAI,Object Position x(202),-1,Object Position z(202)
    AI Add Enemy NoAI
    AI Set Entity Speed NoAI,0
    AI Set Entity View Arc NoAI,160,210
    AI Set Entity View Range NoAI,40
    Categories$(NoAI) = "Adult"

```

```

    XPosition = Object Position x(202)
    ZPosition = Object Position z(202)
    While Object Collision(NoAI,0)
        RandomX = RND(2)-1
        RandomZ = RND(2)-1
        XPosition = XPosition + RandomX
        ZPosition = ZPosition + RandomZ
        Position Object NoAI,XPosition,-1,ZPosition
    ENDWHILE

```

```

Wait 200

```

```

ENDIF

```

```

    If Mouseclick() = 2
    EntitiesOn = EntitiesOn + 1
    NoAI = NoAI + 1
    StageAI = StageAI + 1
    TimeAI = TimeAI + 1

```

```

    Load Object "Media/OldAni.x",NoAI
    Position Object NoAI,Object Position x(202),-1,Object Position z(202)
    AI Add Enemy NoAI
    AI Set Entity Speed NoAI,0
    AI Set Entity View Arc NoAI,140,190
    AI Set Entity View Range NoAI,20
    Categories$(NoAI) = "Old"

```

```

    XPosition = Object Position x(202)
    ZPosition = Object Position z(202)

```

```

While Object Collision(NoAI,0)
  RandomX = RND(2)-1
  RandomZ = RND(2)-1
  XPosition = XPosition + RandomX
  ZPosition = ZPosition + RandomZ
  Position Object NoAI,XPosition,-1,ZPosition
ENDWHILE

Wait 200

ENDIF

If Spacekey() = 1
  Destination = 1
  EntitiesOn = 90
ENDIF

ENDIF

If EntitiesOn = 90
  Destination = 1
ENDIF

Rem *** Set Destination ***
If Destination = 1
  For I = 1 to NoAI
    If Mouseclick() = 1
      Position Object 203,Object Position x(202),-1,Object Position z(202)
      Show Object 203
      DestinationOn = 1
    ENDIF
  NEXT I
ENDIF

Rem *** Start Simulation ***
If DestinationOn = 1
  If Keystate(28) = 1 or Keystate(156)
    Set Object Collision On 203
    Set Object Collision On 201
    EntitiesOn = 91
    For I = 1 to NoAI
      Loop Object I

      If Categories$(I) = "Adult"
        AI Set Entity Speed I,24
      Else
        AI Set Entity Speed I,16
      ENDIF

      StartTime(I) = Timer()/1000
    NEXT
    StartSimulation = Timer()/1000
    Destination = 2
  End If
End If

```



```

    DestinationOn = 2
ENDIF

For I = 1 to NoAI
    AI Entity GO To Position I,Object Position x(203),Object Position z(203)
NEXT I

ENDIF

Rem *** Handle Debugging Output ***
If Keystate(2) = 1 and ptimer < timer()
    ptimer = timer()+300
    pMode = 1-pMode

    If (pMode = 0) then AI Debug Hide Paths else AI Debug Show Paths 2.5
ENDIF

If Keystate(3) = 1 and btimer < timer()
    btimer = timer()+300
    bMode = 1-bMode

    If (bMode = 0) then AI Debug Hide Obstacle Bounds 0 else AI Debug Show Obstacle Bounds
0,2.5
ENDIF

If Keystate(4) = 1 and vtimer < timer()
    vtimer = timer()+300
    vMode = 1-vMode

    If (vMode = 0) then AI Debug Hide View Arcs else AI Debug Show View Arcs 2.5
ENDIF

If Keystate(5) = 1 and atimer < timer()
    atimer = timer()+300
    aMode = 1-aMode

    If (aMode = 0) then AI Debug Hide Avoidance Angles else AI Debug Show Avoidance Angles
2.5
ENDIF

If (Keystate(59) = 1 and f1Timer < timer())
    f1Timer = timer()+300

    F1Pressed = 1-F1Pressed
ENDIF

Rem *** Camera Controls ***
If Downkey() = 1
    CameraZ = CameraZ - 10
    If CameraZ < -500 Then CameraZ = -500
    Position Camera CameraX,CameraY,CameraZ
    Point Camera CameraX,0,CameraZ
ENDIF

```

```

If Upkey() = 1
    CameraZ = CameraZ + 10
    If CameraZ > 500 Then CameraZ = 500
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

If RightKey() = 1
    CameraX = CameraX + 10
    If CameraX > 800 Then CameraX = 800
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

If LeftKey() = 1
    CameraX = CameraX - 10
    If CameraX < -800 Then CameraX = -800
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

Rem *** [Page Up] - Zoom Out ***
If Keystate(201) = 1
    CameraY = CameraY + 10
    If CameraY < 1000 Then CameraY = 1000
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

Rem *** [Page Down] - Zoom In ***
If Keystate(209) = 1
    CameraY = CameraY - 10
    If CameraY < 150 Then CameraY = 150
    Position Camera CameraX, CameraY, CameraZ
    Point Camera CameraX, 0, CameraZ
ENDIF

```

```

Rem *** [Home] - Original Position ***
If Keystate(199) = 1
    CameraX = 0
    CameraY = 800
    CameraZ = -1
    Position Camera CameraX, CameraY, CameraZ
    Point Camera 0, 0, 0
ENDIF

```

```

TimeNow = TIMER()/1000
CurrentTime = TimeNow - StartSimulation

```

```

IF (F1Pressed)
    Rem *** Display Info ***

```

```

Set Cursor 0,0
Print " "
Print "HUMAN MOVEMENT SIMULATION IN NON-BOTTLENECK LAYOUT"
Print " "
Print "No. Of Entities: ",NoAI
Print "No. Of Entities On Stage: ",StageAI
Print " "
Print "Debug Controls:"
Print "[1] Toggle Entity Paths"
Print "[2] Toggle Obstacle Bounds"
Print "[3] Toggle Entity View Arc"
Print "[4] Toggle Entity Avoidance Angles"
Print "Camera Controls:"
Print "  [^] "
Print "[<] [v] [>]"
Print "[PgUp] Zoom Out"
Print "[PgDown] Zoom In"
Print "[Home] Original Position"
Print " "
Print "[ECS] Exit Simulation"
Print " "
Print "FPS: ";Screen FPS()

If Destination = 2
  Print "Time: ",CurrentTime
ENDIF

If TimeAI = -1
  Print "Total Exit Time: ",ExitTime
ENDIF

If EntitiesOn <= 89
  Center Text Screen Width()/2,50,"Please Put Entities Into The Layout. Left Click For Adult,
Right Click For Elderly People"
  Center Text Screen Width()/2,70,"Press SPACEBAR When Enough AI"
ENDIF

If Destination = 1
  Center Text Screen Width()/2,50,"Please Set Destination. Press ENTER to Start Simulation"
ENDIF

If Destination = 2
  Center Text Screen Width()/2,50,"Simulation Started"
ENDIF

If Destination = 3
  Center Text Screen Width()/2,50,"Simulation Ended"
ENDIF

ELSE

Set Cursor 0,0
Print " "
Print "HUMAN MOVEMENT SIMULATION IN NON-BOTTLENECK LAYOUT"
Print " "

```

```

Print "No. Of Entities: ",NoAI
Print "No. Of Entities On Stage: ",StageAI
Print " "

If Destination = 2
  Print "Time: ",CurrentTime
ENDIF

If TimeAI = -1
  Print "Total Exit Time: ",ExitTime
ENDIF

Center Text Screen Width()/2,30,"-- Press F1 For Help --"
If EntitiesOn <= 89
  Center Text Screen Width()/2,50,"Please Put Entities Into The Layout. Left Click For Adult,
Right Click For Elderly People"
  Center Text Screen Width()/2,70,"Press SPACEBAR When Enough AI"
ENDIF

If Destination = 1
  Center Text Screen Width()/2,50,"Please Set Destination. Press ENTER to Start Simulation"
ENDIF

If Destination = 2
  Center Text Screen Width()/2,50,"Simulation Started"
ENDIF

If Destination = 3
  Center Text Screen Width()/2,50,"Simulation Ended"
ENDIF

ENDIF

Rem *** Calculation Time and Kill AI ***
For I = 1 to NoAI
  If Object Hit(203,I)
    EndTime(I) = Timer()/1000
    TravelTime(I) = EndTime(I) - StartTime(I)
    DataLine$ = Str$(I) + "          " + Str$(TravelTime(I)) + "          " + Categories$(I)
    Write String 1,DataLine$
    AI Kill Entity I
    Delete Object I
    StageAI = StageAI - 1
    TimeAI = TimeAI - 1
  ENDIF

If TimeAI = 0
  EndSimulation = Timer()/1000
  ExitTime = EndSimulation - StartSimulation
  TimeAI = -1
  Write String 1, " "
  Write String 1, "Total Exit Time(in Second) is: " + Str$(ExitTime)
  Destination = 3
ENDIF

```

```
If AI Entity Exist(I) = 0
  Make Object Sphere I,10
  Color Object I,RGB(255,0,0)
  AI Add Enemy I
  AI Set Entity Speed I,0
  Position Object I,3000,-1,0
  AI Entity Go To Position I,3000,0
  Hide Object I
ENDIF
```

```
NEXT I
```

```
  AI Update
  SYNC
```

```
LOOP
```

```
Wait Key
END
```