A DISCRETE CHOICE MODEL OF PEDESTRIAN GAP ACCEPTANCE BEHAVIOUR

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ABSTRACT

The purpose of this research is to develop a simulation model for pedestrian gap acceptance behaviour at an uncontrolled mid-block location. This paper first proposes a framework for incorporating pedestrian objects into existing traffic microsimulation. Then within the framework, the pedestrian gap acceptance behaviour is analysed and modelled using a discrete choice approach. A field study was conducted to collect the data of pedestrians' decisions and various possible influencing factors, using a set of synchronised video cameras. This data was used to calibrate and validate the proposed model. The initial results with the model are appealing when considered in combination of simplicity and accuracy. The results can be used to supplement existing guidelines regarding pedestrians or to inspire the inclusion of pedestrian objects into current vehicle-dominated microsimulation tools.

Keywords: pedestrian, gap acceptance, discrete choice, simulation

INTRODUCTION

Walking as a transport mode is healthy, environmentally beneficial and sustainable to human society. Nowadays travellers increasingly are being encouraged to walk more, either as a main mode of travel or as part of a multimodal trip. However, roads can be barriers to pedestrian movement. Pedestrian interaction with motorised vehicles, focused around the road crossing activities, is found to be one of the major constraints to pedestrians (Hine

1996). Vehicular traffic can cause additional delays to pedestrians and pedestrians are extremely vulnerable when they are crossing vehicular lanes. Meanwhile, pedestrian crossing activities also have impacts on the vehicle flow. Such impacts include increased delays, decreased capacity, and harmful environmental influence. For example, although the pedestrian crossing facilities can separate the interaction between the pedestrians and motorised vehicles, it is argued that too many such facilities, inappropriate set-up locations and signal timings can only marginally improve the safety but can significantly lower the efficiency for vehicle traffic and produce more fuel consumption and emissions due to more inconstant flow and stop-and-go phenomena (Hamiltion-Baillie 2008). Besides, the high cost of installation and maintenance for some advanced signalised crossing facilities is also a factor that the decision makers need to consider.

In urban transport, addressing the Pedestrian-Vehicle Interaction (PVI) related problems is a multi-criteria trade-off that the traffic engineers have tackled for a long time. Over the past decades, many innovative treatments (e.g., different pedestrian crossing facilities) have been developed to balance between these two modes. The emerging of various treatments demands proper methods for analysing, evaluating and comparing the performances among one another so that engineers can decide which plan is the best fit for the specific scenario.

Typically, the selection of different treatments is determined by some engineering guidelines and the evaluation of such treatments is carried out through empirical before-after studies. A before-after comparison is often carried out to evaluate the effectiveness of the treatment, in terms of efficiency, safety and environmental impact. While these types of methods are adequate, some researchers argue that the drawbacks of these methods are that the evaluation is time-consuming and lacks microscopic detail (Schroeder 2008); it is impossible to evaluate all potential solutions by implementing them in real systems (Du 2008); and there is a lack of feel what the system will behave if a treatment is adopted before its implementation in reality.

More recently, engineers start to apply the microsimulation as a supplement for existing methods for such evaluation/prediction task to overcome the drawbacks mentioned above. Given a simulation model that mirrors the system in reality, it is possible to derive information about the real system's behaviour just by studying the model's behaviour (Negoita and Ralescu 1987). If properly modelled and validated, the microsimulation can provide detailed evaluation/ prediction results for different sites to assist existing methods for decision making. The performance of the real traffic system being studied can be measured with several model indicators, in terms of efficiency, safety and environmental impact. This provides a non-intrusive and cost-effective way to investigate a real traffic system and permits traffic engineers to have a bird-eye view and an instant feel for the problems and possible solutions (Algers et al 1997).

Apparently, a sound credible simulation model is the key tool for all simulation studies on traffic systems. The core of the microsimulation is the road users' behaviour models. In recent years, although microsimulation models for traffic applications have undergone a long development and most of the motorists' behaviour have been studied and modelled, there are still relatively few studies around pedestrian behaviour and modelling, especially on the PVI process (Harney 2002). Therefore, there are still many limitations for current microsimulation tools to evaluate the operations of pedestrian related traffic systems. For example, common microsimulation tools are of limited use for evaluating the interaction of pedestrians and vehicles at unsignalised locations (Schroeder 2008). The models in current simulation softwares typically ignore the more complex interaction of the two modes in which pedestrians accept gaps in traffic and drivers react to the crossing pedestrians (Schroeder 2008), due to insufficient knowledge to build the microscopic behaviour model. Thus, while most of the existing microsimulation tools may be capable for studying signalised pedestrian crossing, they do not offer a way of studying the PVI behaviour at unsignalised areas or comparing the operations of signalised scenarios to unsignalised scenarios (Schroeder 2008). For these types of studies, some researchers claim that there are needs to develop and integrate separate pedestrian algorithms in traffic microsimulation or to develop new microsimulation software that fully meet the needs to incorporate pedestrians with vehicular traffic. To make this possible there is also a need for better quality and more comprehensive data on pedestrian movement and behavioural characteristics (Ishaque 2006).

Based on the discussion above, a PhD research has been being conducted by the authors around the study of PVI behaviour in the microsimulation environment. This paper presents some parts of this research. It discusses the framework that can be used to incorporate PVI into existing traffic microsimulation, describes the methods of data collection and extraction and some preliminary results of data analysis and modelling, focusing on the pedestrian gap acceptance behaviour, and finally provides the summary and discussion with some directions for future research.

PEDESTRIAN GAP ACCEPTANCE WITHIN PVI ANALYSIS FRAMEWORK

The whole PVI behaviour is defined as the process starting at the moment when a pedestrian emerges at the crossing origin on one side of a road and ending at the moment when the pedestrian finishes the crossing at the crossing destination on the other side of the road. Relevant researches mainly fall into four categories. The most commonly studied behaviour is the pedestrian gap acceptance, which deals with pedestrians' decisions whether or not there is an opportunity to start to cross the road when facing gaps in the vehicle flow. The second category concerns the pedestrians' manoeuvres when they are already on the road, such models include social force model, cellular automaton model and agent based models. Another category focuses on the pedestrians' route choices when crossing a road, usually based on discrete choice models. The last category refers to the researches of motorists' reaction when they are confronted with pedestrians. Most of the studies investigate motorists' yielding behaviour at zebra or signalised crossings but few deal with the situation when motorists interact with pedestrians at pure unsignalised locations.

However, there is not a great amount of guidance in the literature on how to analyse PVI behaviour in a microscopic environment. Existing literature on how to incorporate pedestrians into microsimulation mainly suggests that PVI can be abstracted to pedestrian gap acceptance and motorist yielding behaviour. These types of abstraction mainly consider PVI as discrete processes: for pedestrians, whether or not to cross; and for motorists, no yield, soft yield or hard yield. It does not consider PVI in a detailed continuous fashion, for example, how will a pedestrian approach to the road from origin crossing point, where will he/she decide to cross the road, how will he/she choose velocity according to the dynamics of traffic after making the crossing decision, and what deceleration will the motorist use according to the dynamics of pedestrians. Further, the pedestrian gap acceptance and motorist yielding behaviour are only parts of the whole PVI process. Based on some psychology theory (Zheng 2003), we argued that when a pedestrian emerges at the crossing origin and approaches to the road, he/she may evaluate the scenario and real-time traffic information to generate a rough crossing strategy first (e.g., how to approach to the road and where to cross). This strategic-level process is equally important to the detailed crossing manoeuvre since it may have influence to the traffic performance such as pedestrian delays and the location of frequent conflicting area. It is assumed that only when the pedestrian approaches the vehicle lanes near enough or already on the lanes, can the traffic pressure has major impact on the pedestrian's psychology and behaviour; thus he or she may act more cautiously and exert some tactical-level behaviour such as gap acceptance and velocity choice. Meanwhile, the motorist reacts according to the pedestrian's dynamics with a decision which deceleration to use. Therefore existing analysis suggestion including only pedestrian gap acceptance and motorist yielding is not explicit enough to describe the whole PVI process and can be supplemented by adding up more behaviour modules. We carried out some initial observations to propose a new analysis framework, which divides the whole PVI process into several components to be analysed and modelled. The observation is carried out in Beijing, China, in a section of a 2-way-2-lane-drive-right, single carriage way road. A Cartesian Coordinate System is established as shown in Figure 1. The objective of the observation is to analyse the trajectories of pedestrians crossing the road starting at Φ_1 and ending at Φ_2 to inspire how many behaviour patterns should be analysed and then to establish an analysis framework.

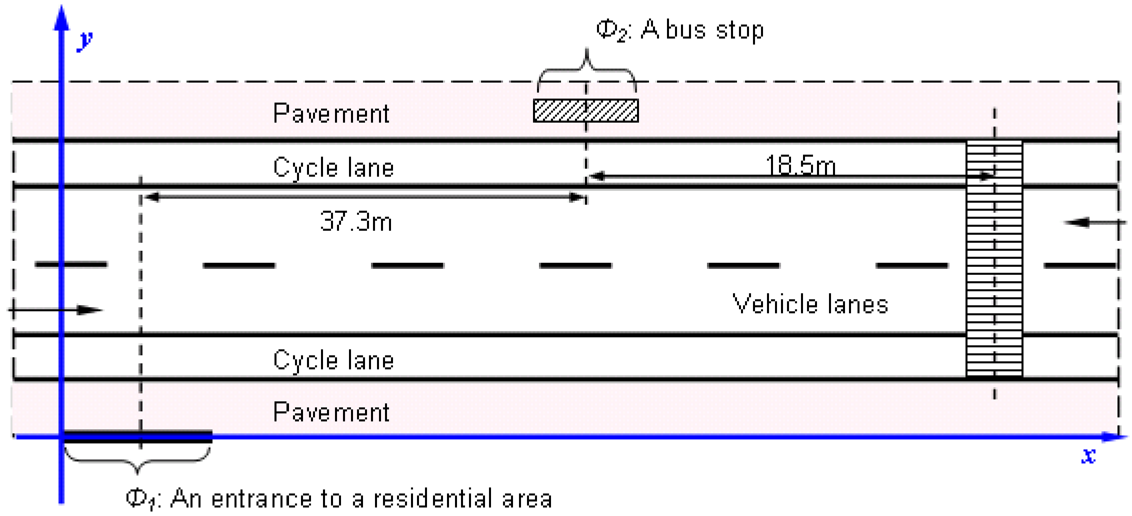

Figure 1 – Initial observation: scenario description

The pedestrians' crossing activities are recorded with four synchronised video cameras and the crossing trajectories are then extracted with a frequency of 0.5Hz. To exclude the influence of cyclists, only samples without adjacent interference of cyclist are used. Pedestrians not walking alone and walking with bikes, luggage or any other similar device are also excluded. Some samples of trajectories of the whole pedestrian crossing processes are drawn in Figure 2.

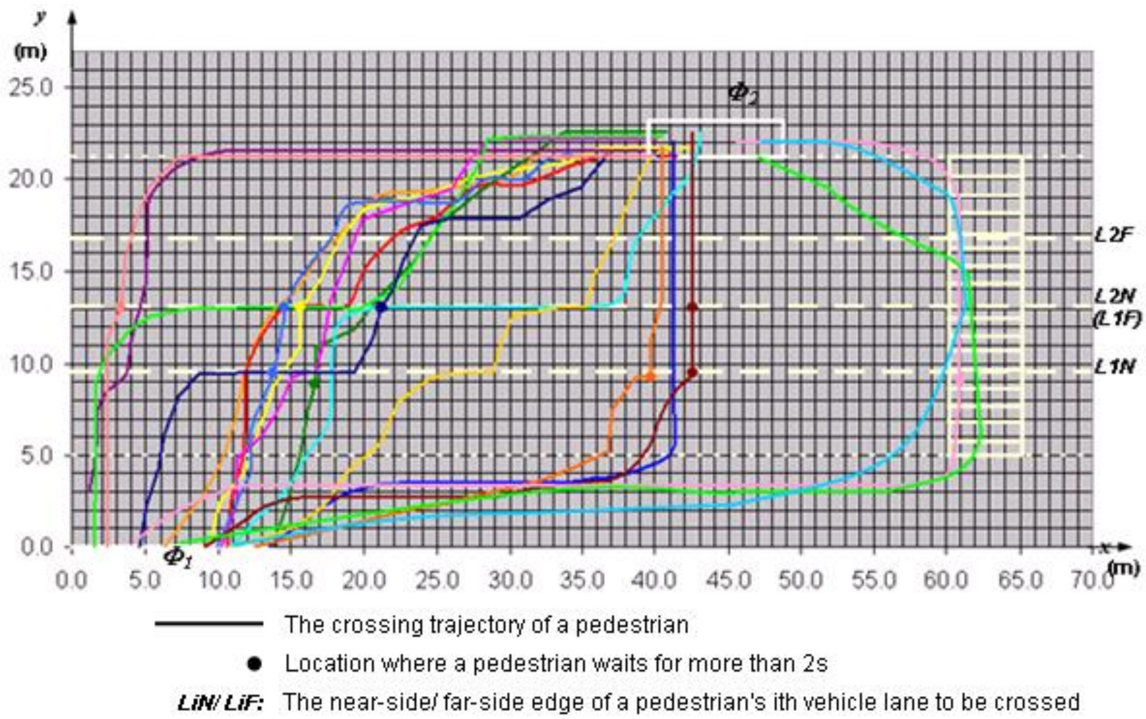

Figure 2 – Initial observation: pedestrian crossing trajectories

It can be seen from Figure 2 that the trajectories of pedestrians crossing the road fall into two categories. The first one is to use the nearby crossing facility and the second one is not to.

Therefore, the first behaviour need to be analysed is whether or not a pedestrian will choose to cross at the nearby crossing facility. This kind of behaviour is abbreviated as PCRC-FC (Pedestrian Crossing Route Choice-Facility Choice). The second fact should be noticed is that for those not to use the crossing facility, their trajectories fall into three sub-categories: to cross near Φ_1, to cross near Φ_2, and to cross between Φ_1 and Φ_2. It is also noted that for a single pedestrian, the first point at which the pedestrian stops to wait appears mostly at the near-side edge of the first vehicle lane (*L1N*) due to the fact that there is no available gap for the pedestrian to increase his/her y coordinate when he/she arrives at *L1N* (as a result, he/she stops to wait or keeps walking just along the positive direction of the x axis). When the pedestrian arrives at *L1N*, he/she may exert more tactical behaviour, such as gap acceptance. To simplify the problem, the *L1N* is defined as the boundary of PCRC-VC (Pedestrian Crossing Route Choice-Velocity Choice) and PCM-GA (Pedestrian Crossing Manoeuvre-Gap Acceptance), two new modules to be included. Although it is difficult to learn exactly where a pedestrian starts to exhibit the gap acceptance behaviour, it is noted that the pedestrian has more freedom with his/her movement in the y direction when he/she has not reached *L1N*. When the pedestrian arrives at *L1N*, whichever behaviour he/she exhibits (e.g., stepping into the vehicle lane, moving along the vehicle lane or stopping completely to wait), his/her decision here can be regarded as the gap acceptance. This concept is also applicable when the pedestrian arrives at *LjN* ($1 < j \le n$; n is the total number of lanes of the road). Therefore in this research, the PCM-GA is specifically referred as the pedestrian's gap acceptance behaviour when $y_{Ped} = y_{LiN}$ ($1 \le i \le n$; n is the total number of lanes of the road) (In this paper, we only discuss the situation when $y_{Ped} = y_{L1N}$, which means the pedestrian faces 2 vehicle lanes to be crossed). After the pedestrian rejects or accepts a gap, the pedestrian then can make a movement. This sub process is abbreviated as PCM-VC (Pedestrian Crossing Manoeuvre-Velocity Choice). The data requirement and analysis for this module is similar to PCRC-VC, with an exception that the data sample for this module should come from the interval $y_{L1N} \le y_{Ped} \le y_{LnF}$. Finally, when the pedestrian approaches the vehicle lane, the driver can have a perception about the pedestrian's dynamics and then react to the pedestrian. The reactions from the motorists can be categorised into two types. First, when the pedestrian is waiting on the near-side edge of the vehicle lane but has not step into the lane yet, some percentage of the drivers is willing to yield to this pedestrian (active reaction). Second, when the pedestrian is already on the vehicle lane, the incoming vehicle in this lane has to react (e.g., whether to decelerate or not, which deceleration rate to use) to the pedestrian according to his/her status in order to avoid potential collision (passive reaction). These types of motorists' behaviour are abbreviated as MOR (MOtorists Reaction). To summarise, the analysis framework for PVI study should consist five behaviour modules (Figure 3). The following contents will discuss the methods of relative data collection and extraction, as well as some preliminary analysis and modelling results, with the focus on PCM-GA module, which is the most important one in this framework.

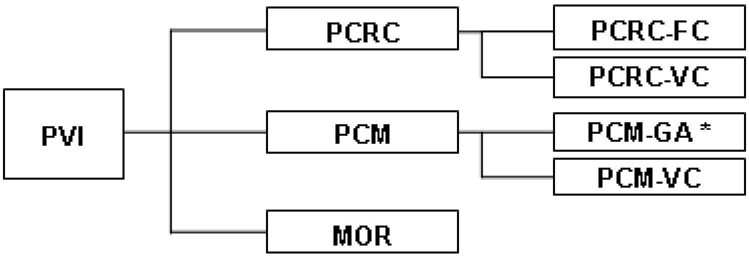

Figure 3 – Analysis framework for PVI study (* indicates the module to be studied in this paper)

PVI – Pedestrian-Vehicle Interaction; PCRC – Pedestrian Crossing Route Choice; FC – Facility Choice; VC – Velocity Choice; PCM – Pedestrian Crossing Manoeuvre; GA – Gap Acceptance; MOR – Motorist Reaction

METHODOLOGY

As discussed above, in the process of pedestrian gap acceptance, the pedestrian has two alternatives: to accept and get ready to start to cross or to reject. Therefore, a discrete choice model is appropriate to model this process. Since only two alternative decisions are made, a binary logit model was considered appropriate. Similar models have gained attention for studying similar problems, for example Sun et al (2003) studied the pedestrians' gap acceptance behaviour at a zebra crossing using a binary logit model. However, the gap acceptance behaviour in pure unsignalised conditions (e.g., jaywalking) has not been studied as explicitly as those with certain types of pedestrian crossing facilities. For the PCM-GA in this study, the decision of a pedestrian is either to accept a gap or to reject it. This decision making process is modelled with the binary logit model (an individual choice with two alternative outputs). The probability of choosing an alternative is based on a linear combination function (utility function) expressed as:

$$U_i=\alpha_i+\beta_{i1}X_1+ \beta_{i2}X_2+ \ldots+\beta_{in}X_n, \quad (1)$$

Where,
U_i = the utility of choosing the alternative i;
i = the alternative i;
n = the number of independent variables;
α = constant;
$\beta_1, \ldots \beta_n$ = coefficients.

The utility of alternative i has to be transformed into a probability in order to predict whether a particular alternative will be chosen or not. The probability of choosing alternative i is then calculated with the following function:

$$P(i=1)=1/[1+exp(-U_i)] \quad (2)$$

For a decision making involving two choices A and B, the probability of choosing A is given as:

$$P_{Ai}=exp(U_{Ai})/[exp(U_{Ai})+exp(U_{Bi})]=1/\{1+exp[-(U_{Ai}-U_{Bi})]\} \quad (3)$$

Where,
$U_{Ai}-U_{Bi} = \beta(Z^{Ai}-Z^{Bi})= \beta Z^{i}$;
β = row vector of parameters (coefficient of variables) to be estimated;
Z^{ji} = column vector of attributes of individual i and characteristics of mode j.

The calibration and validation of the binary logit model involves the determining the parameter vector β, which is achieved by using the data collected onsite. For a preliminary study, we incorporate six possible influencing variables to calculate the utility function that captures the decision making process (i = 0: rejecting a gap, i = 1: accepting a gap) in PCM-GA, including:

- *Age*: pedestrian's age category (0: YOUNGER, 1: OLDER);
- *Gender*: pedestrian's gender category (0: MALE, 1: FEMALE);
- *WTime*: pedestrian's waiting time (s);
- *PedNum*: number of pedestrians in a crossing group;
- *NearGap*: near-side gap size in the vehicle lane (s);
- *FarGap*: far-side gap size in the vehicle lane (s).

Hence, the general form of the binary logit model for PCM-GA is:

$$\begin{cases} U_1 = \alpha + \beta_1 Age + \beta_2 Gender + \beta_3 WTime + \beta_4 PedNum + \beta_5 NearGap + \beta_6 FarGap \\ P(i=1) = 1/[1+exp(-U_1)] \end{cases} \quad (4)$$

The idea is to test the relationship between the pedestrians' decision output and the above behavioural factors. The data required for analysing and modelling the PCM-GA include the static site characteristics and the microscopic dynamics of the pedestrians and vehicles. The former can be easily obtained through field survey with measuring tools, while the latter can be collected by video camera recording with manual data extraction, which promises a good trade-off among flexibility, accuracy and efficiency, and also provides the opportunity for the researcher to trace back to the original event scenarios. For this method, first, the raw video data are collected with several synchronised video cameras. Then all the data of interest can be extracted manually by comparing the relative position of the subjects to nearby road markings, with the help of common video processing software.

A 2-way-2-lane single carriage way road section with no pedestrian crossing facility in Beijing, China is selected to collect the data. Figure 4 shows a schematic diagram of the data collection set-up.

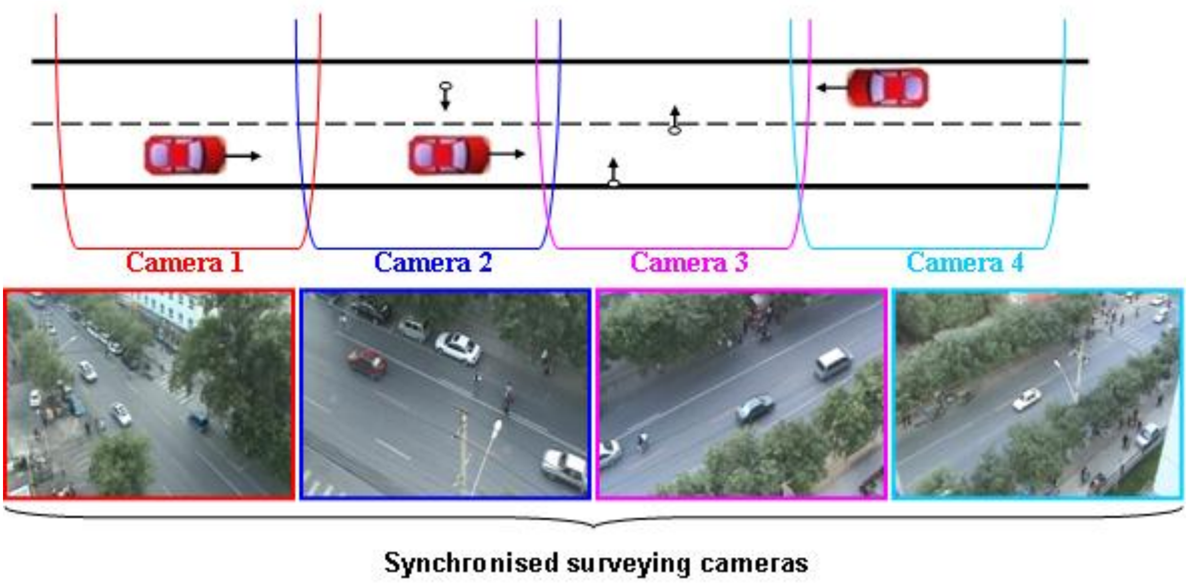

Figure 4 – Data collection set-up for PCM-GA

The static characteristics of the site (e.g., road geometry, length of road markings and width of vehicle lanes) are surveyed using a measuring wheel. The dynamic traffic scenario is recorded by four synchronised video cameras with 25Hz recording frequency for each. Two cameras cover the frequent interaction area for most of the PVI behaviour data and two others cover both sides of the area with relatively along distances to record the concurrent vehicle dynamics. The four video cameras can cover a road section of approximate 200m long. The static data of each pedestrian/vehicle such as the pedestrian's gender and age category and number of pedestrians in a group can be clearly observed from the video pictures. The dynamic traffic data such as pedestrians' waiting time, near-side and far-side gaps can be manually extracted with the help of video processing software with acceptable errors. The data analysis and modelling process for PCM-GA is described in the next section.

DATA ANALYSIS AND MODELLING RESULTS

A total of 600 data set was used, with 70% for estimating the coefficient of the regression function and 30% for model validation. A multiple variable regression analysis was performed in SPSS, which estimates the coefficients of the linear utility function using the maximum likelihood method. Table I shows the result of coefficient estimation.

Table I – Estimated coefficients

	β	S. E.	Wald	*df*	Sig.	Exp (β)
Age	-2.225	0.847	6.891	1	0.009	0.108
NearGap	1.389	0.226	37.859	1	0.000	4.012
PedNum	0.619	0.309	4.007	1	0.045	1.858

Constant	-7.207	0.852	38.822	1	0.000	0.005

* This table shows only three variables of the proposed six are significant enough to be included in the final model.

Therefore, using the regression on the collected data, the model expressed with equation (4) can then be calibrated as:

$$\begin{cases} U_1 = -7.207 - 2.225Age + 0.619PedNum + 1.389NearGap \\ P(i=1) = 1/[1+exp(-U_1)] \end{cases} \quad (5)$$

Table II shows the modelling and validation results. The validation is performed against 30% of the total data prepared and the result shows that in the validation process the percentage of the overall correct prediction of the above binary logit model is 91.0%.

Table II – Modelling and validation results

Observed		Predicted					
		Cases for modelling			Cases for validation		
		PGA		Percentage correct	PGA		Percentage correct
		0	1		0	1	
PGA	0	300	10	96.8	98	8	92.5
	1	20	114	85.1	6	44	88.0
Overall percentage		N/A	N/A	93.2	N/A	N/A	91.0

DISCUSSION

For the PCM-GA module under pure unsignalised condition, three factors including near-side traffic gap, pedestrian's age category and number of pedestrians in a crossing group, out of six proposed ones, are identified significant enough to be included into the binary logit model. The fact that the factor of pedestrian's waiting time is left out is not surprising because it has been found by different researchers when they studied the pedestrians' gap acceptance behaviour at marked crossing facilities that the increase of waiting time could result in either shorter or larger accepted gaps. Some researchers explained it as that pedestrians tend to exhibit more risky behaviour when waiting a longer time while others are in favour that the pedestrians who still wait at the kerbside after long waiting time tend to be careful in nature and therefore would hardly accept a short or risky gap.

(1) The effect of time gap on gap acceptance:

The near-side time gap is a significant influencing factor to the pedestrians' gap acceptance behaviour. If the variable *PedNum* is fixed to 1, the predicted probability of accepting a gap for a single pedestrian in the binary logit model is shown in Figure 5. Compared to the near-side gap, the far-side gap is not significant. This means that in reality the jaywalking pedestrians hardly pay attention to the far-side incoming vehicles when they start to cross the first lane. In fact, when we traced back to the raw video data, we found that many pedestrians cross the road regardless of the far-side gap, even when the far-side gap is too small to be utilised, resulting in the fact that such pedestrians wait at the middle of the road for the next possible gaps in the far-side lane to continue to cross the road. And this can be regarded as a potential dangerous behaviour as there are no special facilities providing protection to the on-road crossing pedestrians.

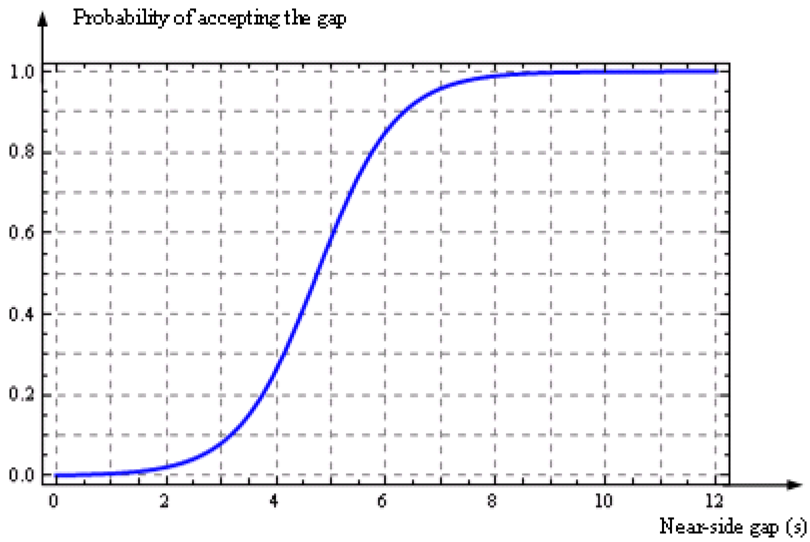

Figure 5 – Probability of the pedestrian's gap acceptance (*PedNum* = 1, *Age* = YOUNGER)

(2) The effect of age on gap acceptance:

To analyse the difference in the gaps accepted by age groups, we divided the data based on age into two groups: older pedestrians (i.e., those who appear to be 65 years or older) and younger pedestrians (i.e., those who appear to be between 20 and 50 years). A pedestrian's age category is estimated by the researchers conducting the data collection, excluding those whose age group can not easily be determined by the researchers. Although this method is subjective than the pedestrians' self reported data, it is by far the practical way to obtain those data when the subjects to be surveyed are kept unaware and it is accepted by peers in this research area. Figure 6 shows the results from gaps accepted by both these groups of pedestrians (for a single pedestrian). It can be seen that when other factors are kept constant, older pedestrians are more cautious and wait for a longer near-side gap to start the crossing, resulting in more pedestrians' delays when there are no sufficient number of available gaps on the near-side vehicle lanes during peak hours.

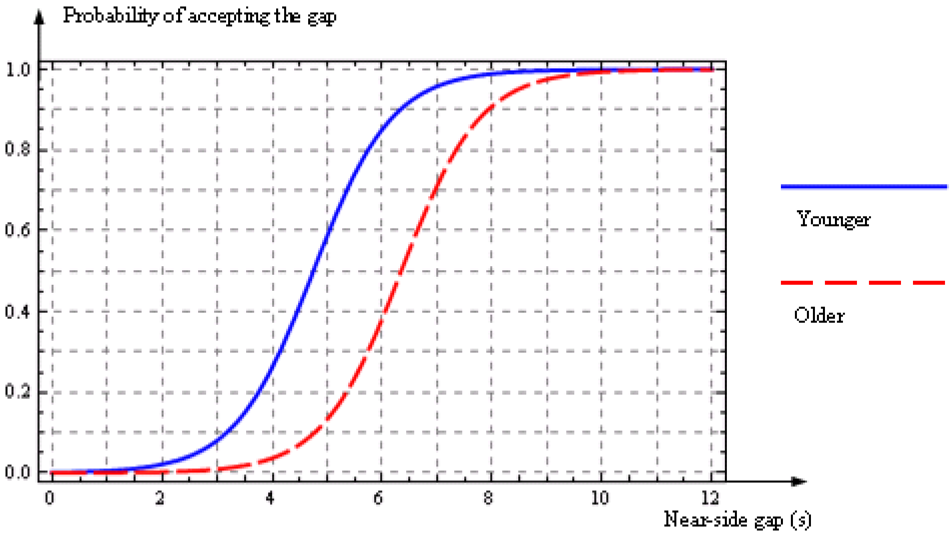

Figure 6 – Probability of the pedestrian's gap acceptance (*PedNum* = 1)

(3) The effect of group size on gap acceptance:

The effect of group size on pedestrians' gap acceptance behaviour is shown in Figure 7. It can be seen that as the number in a waiting group increases, the pedestrians become more aggressive and thus may accept smaller gaps. One possible explanation is that when a particular pedestrian is surrounded by several other pedestrians, he/she may feel protected by others and then may act more aggressively. However, the more complex effect of the grouping behaviour on the gap acceptance has not been extensively studied at current stage. For example, the position of a pedestrian in a waiting group may have different effects on the gap acceptance behaviour. Further exploration needs more data sets with the pedestrians' grouping behaviour.

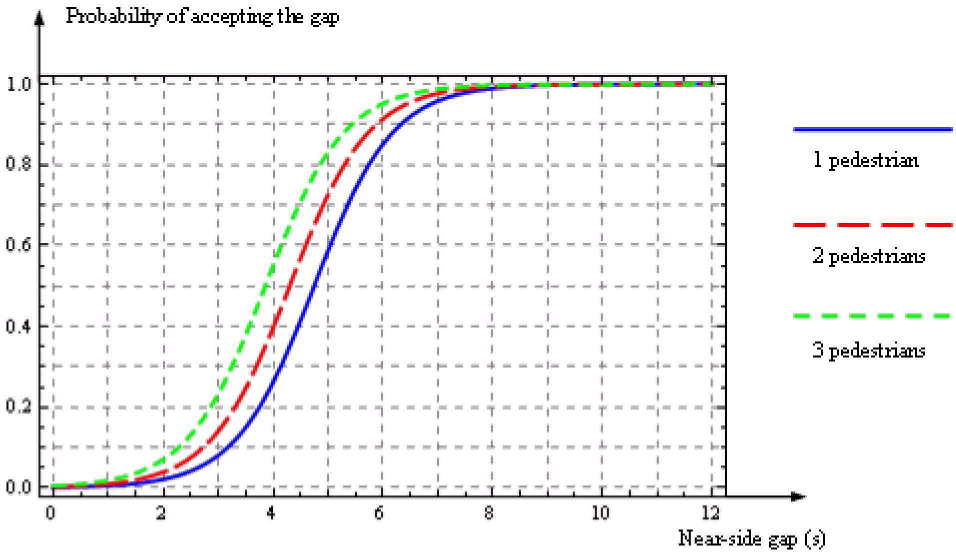

Figure 7 – Probability of the pedestrian's gap acceptance (*Age* = YOUNGER)

SUMMARY

This paper proposes an analysis and modelling framework for incorporating the PVI into existing traffic microsimulation, based on non-intrusive observations from real PVI scenarios. Five modules are proposed to be included for the study of PVI process. With the focus on the pedestrian gap acceptance process under pure unsignalised condition, this paper presents some initial results of behaviour study and modelling, using binary logit technique. Three factors including near-side traffic gap, pedestrian's age category and number of pedestrians in a crossing group, out of six proposed ones, are identified to be significant enough to be included into the binary logit model. The initial results with the logit model are appealing when considered in combination of its simplicity and accuracy. Future research may involve the inclusion of more possible influencing factors and larger data sets. In addition, PCM-GA is only one part of the whole proposed PVI framework, more behaviour studies are to be carried out to fully incorporate the PVI process into existing traffic microsimulation. The benefits of such researches are twofold. First, some fundamental understanding of PVI behaviour will be gained and this knowledge can form guidelines for planning and engineering strategies for pedestrian related transport in the future. Second, this knowledge can be interpreted and integrated into existing microsimulation models, with which various design, management and control plans can be tested and evaluated. Considering both pedestrians and vehicles, detailed indicators of efficiency, safety and environmental impact can be generated and presented, vividly and cost-effectively, in a microsimulation environment, as a supplement for existing engineering tools.

REFERENCES

Algers, S. et al (1997) *Review of microsimulation models*. SMARTEST Project Deliverable D3, Institute for Transport Studies, University of Leeds, Leeds, UK. Available from: http://www.its.leeds.ac.uk/projects/smartest/deliv3.html#a2 [Accessed 25 June 2008].

Du, Y. (2008) Simulation Study of Different Operations of Mixed Traffic With Motor Vehicles and Bicycles at AT-grade Intersections in Beijing, China. Dissertation (PhD (Civil Engineering)), University of Southampton, United Kingdom.

FHWA (1998) *CORSIM User Manual (1.04 ed.).* Federal Highway Administration, US Department of Transportation, McLean, Virginia.

Hamiltion-Baillie, B. (2008) Shared Space: Reconciling People, Places and Traffic. *Built environment,* 34 (2), 161-181.

Harney, D. (2002) *Pedestrian modelling: Current methods and future directions.* Road & Transport Research: Journal of Australian and New Zealand Research and Practice, 11 (4), 38-48.

Hine, J. (1996) Pedestrian travel experiences: assessing the impact of traffic on behaviour and perceptions of safety using an in-depth interview technique. *Journal of Transport Geography,* Vol. 4, pp. 179-199.

Ishaque, M. M. (2006) *Policies for Pedestrian Access: a Multi-modal Trade-off Analysis using Micro-simulation Techniques.* Dissertation (PhD (Civil Engineering)). University of London, United Kingdom.

Negoita, C. V. and Ralescu, D. (1987) *Simulation, Knowledge-based computing, and Fuzzy Statistics.* New York: Van Nostrand Reinhold Company Inc.

Schroeder, B. J. (2008) *A Behaviour-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalks.* Dissertation (PhD (Civil Engineering)), North Carolina State University, United States.

Sun, D. et al (2003) *Modeling of Motorist-Pedestrian Interaction at Uncontrolled Mid-block Crosswalks.* Submitted for Publication in Transportation Reseach Record, TRB 2003 Annual Meeting CD-ROM. Washington, DC.

Zheng, P. (2003) A Microscopic Simulation model of Merging Operation at Motorway On-ramps. Dissertation (PhD (Civil Engineering)). University of Southampton, United Kingdom.