

**Zhen YANG**, Ph.D.<sup>1</sup>  
(Corresponding author)  
E-mail: zyang\_2016@163.com

**Jianxiao MA**, Ph.D.<sup>1</sup>  
E-mail: majx@njfu.edu.cn

**Baojie WANG**, Ph.D.<sup>2</sup>  
E-mail: wangbj2@163.com

**Xingchen YAN**, Ph.D.<sup>1</sup>  
E-mail: xingchenyan.acad@gmail.com

<sup>1</sup> College of Automobile and Traffic Engineering  
Nanjing Forestry University  
159th Longpan Road, Nanjing City,  
Jiangsu 210037, China

<sup>2</sup> College of Transportation Engineering  
Chang'an University  
Middle Section of Nan'er Huan Road,  
Xi'an City, Shaanxi 710064, China

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# APPLICATION OF PEDESTRIAN UPSTREAM DETECTION STRATEGY IN A MIXED FLOW TRAFFIC CIRCUMSTANCE

## ABSTRACT

*Walking is an environment-friendly trip mode and can help ease the congestion caused by automobiles. Proper design of pedestrian facilities that promotes efficiency and safety can encourage more people to choose walking. Upstream detection (UD) strategy is proposed by previous studies to reduce pedestrian waiting time at mid-block crosswalk (MBC). This paper applied UD strategy to MBC under mixed traffic circumstance where the crosswalk serves both pedestrians and non-motor users. Traffic data was collected from an MBC in the city of Nanjing, China. Simulation models were developed by using the VISSIM software and its add-on module Vehicle Actuated Programming (VAP). The models were categorised by the volume and composition of pedestrians and non-motor users. Models were simulated according to different experimental schemes to explore the effectiveness of the UD strategy under mixed traffic circumstance. T-test and analysis of variance (ANOVA) were used to interpret the simulation results. The main conclusions of this paper are that the UD strategy is still effective at the MBC with a mixed traffic circumstance despite the proportion of non-motor users. However, as the proportion of non-motor users becomes higher, the average delay of pedestrians and non-motor users will increase compared to pure pedestrian flow.*

## KEYWORDS

*mid-block crossing; upstream detection; pedestrian; non-motor traffic; VISSIM; delay.*

## 1. INTRODUCTION

Walking is a basic transportation mode that primarily serves the "last-mile" of other modes. In recent years, due to the rapid growth of the number of automobiles, the travel environment is becoming more and more crowded. In such situation, many transportation agencies around the world have emphasised the importance of raising people's willingness to walk within reasonable travel distance. On the one hand, walking is an eco-friendly mode which is good for people's health; on the other hand, walking can help to ease the congestion brought by automobiles [1].

To encourage more people to choose walking, a proper design of facilities to promote the efficiency and safety of pedestrians is indispensable. Mid-block crosswalk (MBC) is a type of pedestrian facility that is mainly installed between two adjacent intersections to improve the accessibility to pedestrians [2]. MBC is especially necessary when the distance between intersections is long and the crossing opportunity is insufficient. Common treatments of MBC include pavement markings, driver warning signs, in-roadway warning lights, traffic calming measures (e.g. curb extensions and raised crosswalk), flashing beacons (e.g. rectangular rapid-flashing beacon), and traffic signals [3–6].

Compared to other treatments, traffic signal clearly specifies the temporal right-of-way of traffic users. Typical signalised MBCs are conventional pedestrian-actuated crossing (PA), pedestrian light-controlled crossing (PELICAN), pedestrian user-friendly intelligent crossing (PUFFIN), and pedestrian hybrid beacon (PHB) [7]. The four types of MBC operate in a semi-actuated mode with installed push buttons for pedestrians to activate their crossing phase. The phase schemes of these MBCs are shown in *Figure 1*, where we can see that they follow similar control logic. Under the default state (when there is no pedestrian), motor vehicles have the right-of-way at the crosswalk. When pedestrians activate the signal by pressing the push button, the vehicle clearance time is launched and the crosswalk turns to serve the pedestrians. The pedestrian signal consists of pedestrian “Walk” signal and clearance time. After it terminates, the right-of-way is given back to motor vehicles until the signal is activated again. Two consecutive activations of pedestrians should meet the requirement of minimum vehicle green.

A considerable number of research was conducted on the control strategy and traffic behaviour of signalised MBC. It has remained a hot topic. Fitzpatrick and Pratt investigated the actual behaviours of drivers and pedestrians at crosswalks with PHBs under various road and traffic conditions. They found that the average driver yielding percentage is 96%, and 91% of the pedestrians use the push button to cross the road [8]. Kim et al. examined the critical pedestrian

flow below which the crosswalk with push button can effectively reduce the total delay of all traffic users [9]. Zhao et al. proposed an integrated optimisation model that can deal with the location of MBC and vehicular red time at the downstream intersection [10]. Wang et al. investigated the heterogeneity of vehicle yielding behaviour at a semi-controlled crosswalk. It was found that buses perform well in observing pedestrian dynamics, while private cars do not perform well in yielding to pedestrians [11]. Kutela and Teng analysed the situations on which drivers tend to yield to pedestrians and pedestrians are willing to press the push button at signalised mid-block offset crosswalks [12].

The installation of MBC has a negative impact on roadway capacity and traffic progression [13]. Dhmaniya and Chandra investigated a six-lane divided urban road and found that the roadway capacity will be reduced by 30% when the pedestrian volume at MBC increases to 1,360 per hour [14]. For this reason, the MBC signal is specially designed to reduce unnecessary delay of vehicles. As shown in *Figure 1*, the PELICAN shows a flashing amber signal to drivers after a period of pedestrian clearance time. This is to inform the drivers to proceed carefully if pedestrians have passed the conflict area [15]. Similar process can be found in PHB, but the flashing amber is replaced by an alternating flashing red indicator [8]. The PUFFIN introduces kerbside detectors for vehicular efficiency and on-crossing detection for the safety concern. The kerbside detector can cancel

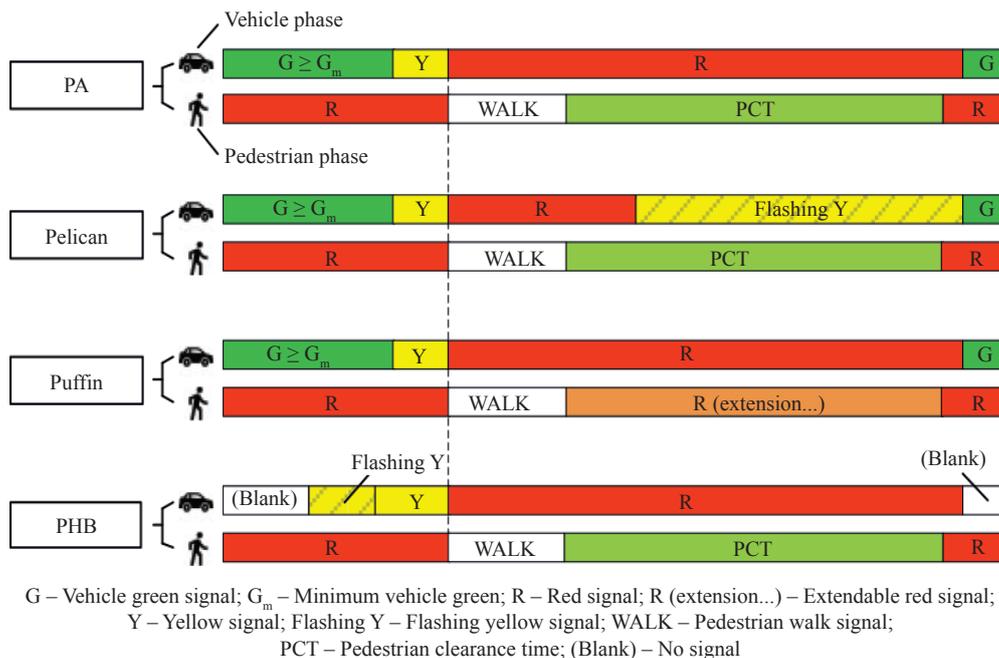


Figure 1 – The phase schemes of four types of MBCs

the demand if pedestrians have moved away before the start of their phase. On-crossing detection is installed to extend the pedestrian phase if pedestrians are still trapped on the crosswalk at the end of clearance time [15].

However, the improvement of pedestrian delay at MBC has not yet received enough consideration. In fact, pedestrians always experience long waiting time after they press the button, because minimum green and clearance time for vehicles should be operated first. Long waiting time has a negative impact on pedestrians' compliance with the signal rule. The 2010 Highway Capacity Manual (HCM) states that there is a high likelihood of pedestrians not complying with the signal indication if they experience delays in excess of 30 seconds. In contrast, pedestrians are very likely to comply with the signal indication if their expected delay is less than 10 seconds [16]. Van Houten et al. also found that pedestrian compliance is inversely correlated with minimum green time for vehicles. This is evident at locations with lower average daily traffic and one-way traffic [17]. Long waiting time can also be depressing for pedestrians and makes walking unattractive.

To reduce pedestrian delay at MBC, Hassan et al. first proposed the concept of upstream detection (UD) strategy and applied it to PUFFIN crosswalk [18–20]. The idea of UD strategy is just like the placement of vehicle detector at the upstream position of an intersection to activate the signal in advance, except that the detector is replaced by a push button to serve pedestrians. As shown in Figure 2,

extra push buttons are placed on the upstream positions of the crosswalk so that pedestrians can activate their phase before they reach the crosswalk. The buttons at the entrance of the crosswalk are still retained in case that the pedestrians miss the “Walk” signal. Besides, communication devices should be equipped to connect the upstream detector with the signal controller. Hassan et al. [18] determined the optimal location of upstream detector for PUFFIN and found that the implementation of a UD strategy generates more signal cycles. Besides, pedestrian delay is reduced while vehicular delay becomes higher. Yang et al. [21] applied a UD strategy to MBC signal with the logic of PHB. They found that average pedestrian delay is reduced by 7% to 38% depending on the pedestrian volume and crosswalk length, while average vehicular delay is increased by 3% to 6% only. The results show that the UD strategy not only reduces pedestrian delay, but also increases systematic benefit.

According to the authors' current knowledge, only a few studies have dealt with the UD strategy for pedestrians. The limitation of these studies is that they assume the traffic flow across the road is pure pedestrian flow. In fact, in many developing countries (like China), the crosswalk not only serves pedestrians, but also non-motor vehicles like bicycles and e-bikes, i.e., the crosswalk presents a mixed traffic circumstance. Many bicycles and e-bike users also use the push button to cross the road. As there are evident speed differences

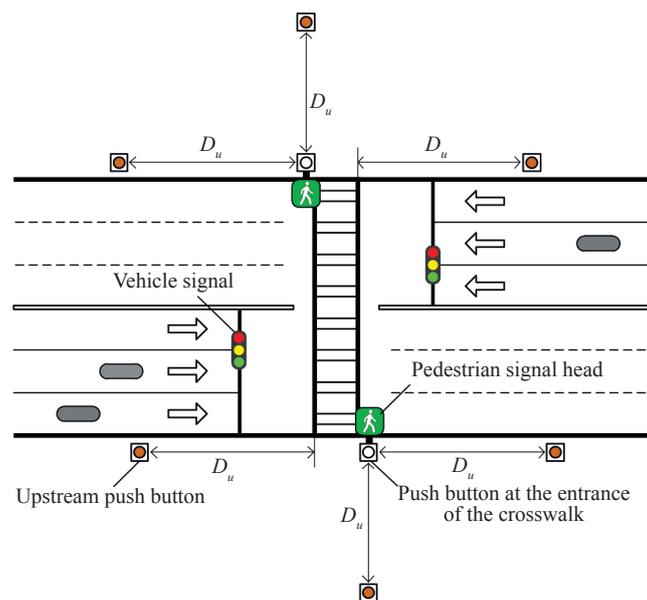


Figure 2 – Pedestrian upstream detection (UD) strategy for MBCs

between non-motor vehicles and pedestrians, it is necessary to examine whether the UD strategy is still effective under mixed traffic circumstance.

### 2. RESEARCH OBJECTIVES

The primary goal of this study is to examine the effectiveness of the UD strategy for MBC under mixed flow traffic circumstance, or to find out whether the UD strategy is still applicable for mixed traffic circumstance. To achieve this goal, a typical MBC in China was selected to collect traffic data. Microscopic traffic simulation software VISSIM and its add-on module Vehicle Actuated Programming (VAP) were used to simulate the operation of MBC. Different experimental schemes considering the variations of traffic volume and composition (the proportion of pedestrians and that of non-motor vehicles) were developed to investigate the performances of MBC. Finally, the conclusion is drawn by using statistical approaches.

### 3. DATA COLLECTION

The data used for this study were collected from an MBC located in an arterial road named Longpan Road in the city of Nanjing, China. The arterial road is bi-directional and has four lanes in each direction. The location and geometric size (including the length of the crosswalk, the distance between the stop line, and the far-side edge of the crosswalk) of the selected MBC are illustrated in *Figure 3*. High-resolution cameras were used to record videos of this MBC at peak hour (17:00–18:00) on weekday. The volume and composition of motor vehicles (which is shown in *Table 1*) were manually counted from the videos.

The speed data of all traffic users, including motor vehicles, non-motor vehicles, and pedestrians, were extracted from the videos by using the KMplayer software. *Figure 4* illustrates the speed extraction process for vehicles. Two reference points are set at the stop line and the far-side edge



Figure 3 – The location and geometric size of the selected MBC

Table 1 – The volume and composition of motor vehicles at the selected MBC

Direction	Traffic volume [veh]	Traffic composition
Northbound	1265	92.41% cars, 4.82% buses, 1.98% trucks, 0.79% mopeds
Southbound	1402	93.44% cars, 5.42% buses, 0.93% trucks, 0.21% mopeds



Figure 4 – The speed extraction process for vehicles by using the KMplayer software

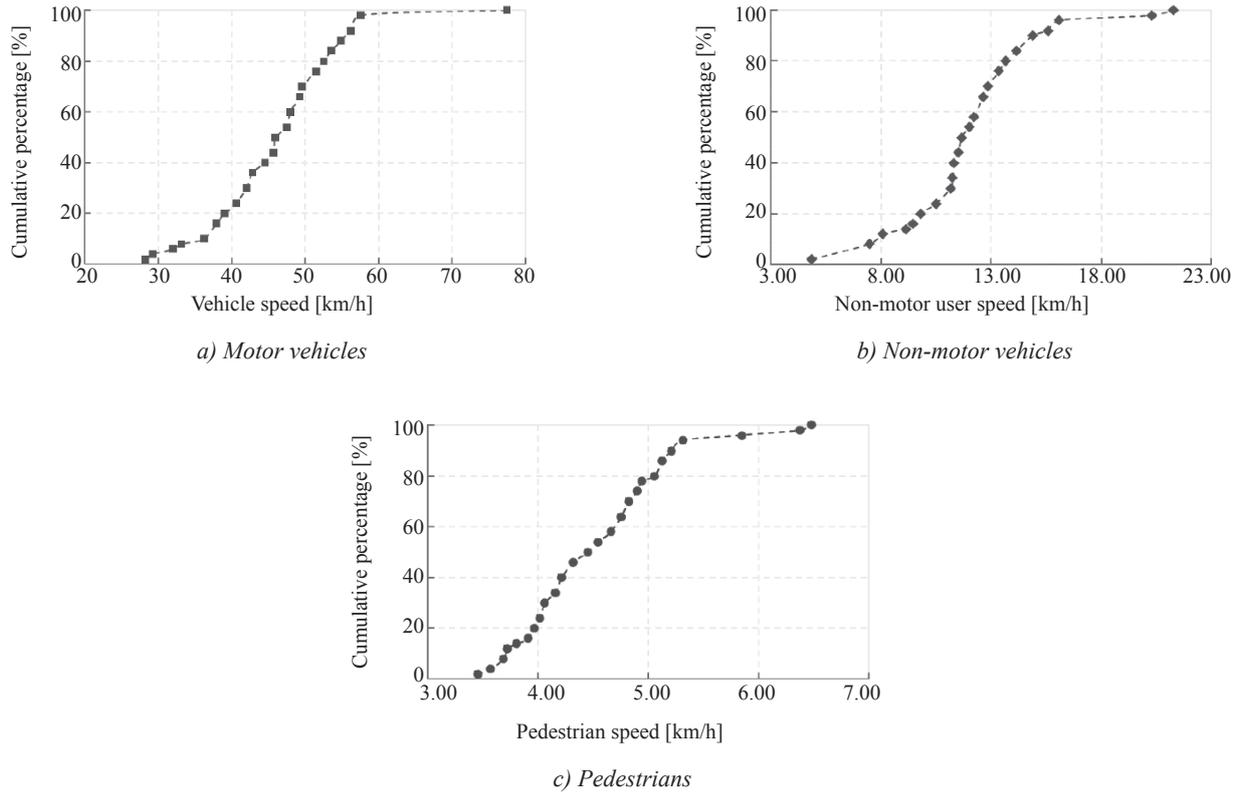


Figure 5 – The speed distribution of traffic users at the selected MBC

of the crosswalk, respectively. The times that each vehicle passes two reference points at the green period can be read on the software. As the distance is known, the speeds of sample vehicles can be obtained. For pedestrians and non-motor users, the speed extraction process is similar. Figure 5 illustrate the cumulative speed distributions of all traffic users.

Currently, the selected MBC is operated in a semi-actuated mode, which is very similar to the PA in Figure 1, but differs in the following aspects: (1) Pedestrian signal shows a green man, without clearly distinguishing the “Walk” time and pedestrian clearance time;

(2) The last 8 seconds of pedestrian green period shows a flashing green man to warn pedestrians of green termination.

## 4. METHODOLOGY

### 4.1 Model input

In the following text, VISSIM and its add-on module VAP were used to develop models to simulate the operation of the selected MBC. Model calibration process mainly refers to the research of Ma et al. [22]. The initial settings and incorporated driving behaviour parameters are shown in Table 2.

Table 2 – The initial settings and incorporated driving behaviour parameters of MBC models

The initial settings			
Signal stages	Vehicle, pedestrian*	Initial active stage	Vehicle
Amber time for vehicles [s]	3		
The incorporated driving behaviour parameters			
Observed vehicles	2	Minimum look-ahead distance [m]	20
Average standstill distance [m]	2	Additive part of safety distance [m]	2.5
Multiplicative part of safety distance [m]	3.5	Waiting time before diffusion [s]	60
Minimum headway [m]	0.5		

\*There are two pedestrian stages in the model as explained in the following text. One is normal, and the other sets the last 8 seconds as red.

A picture of the models is illustrated in *Figure 6* in 3D mode. The phase scheme of the selected MBC and the procedure of the VAP program are described in *Figure 7*.

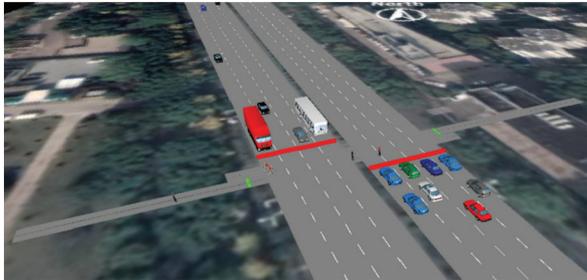


Figure 6 – A picture of the VISSIM model in 3D mode

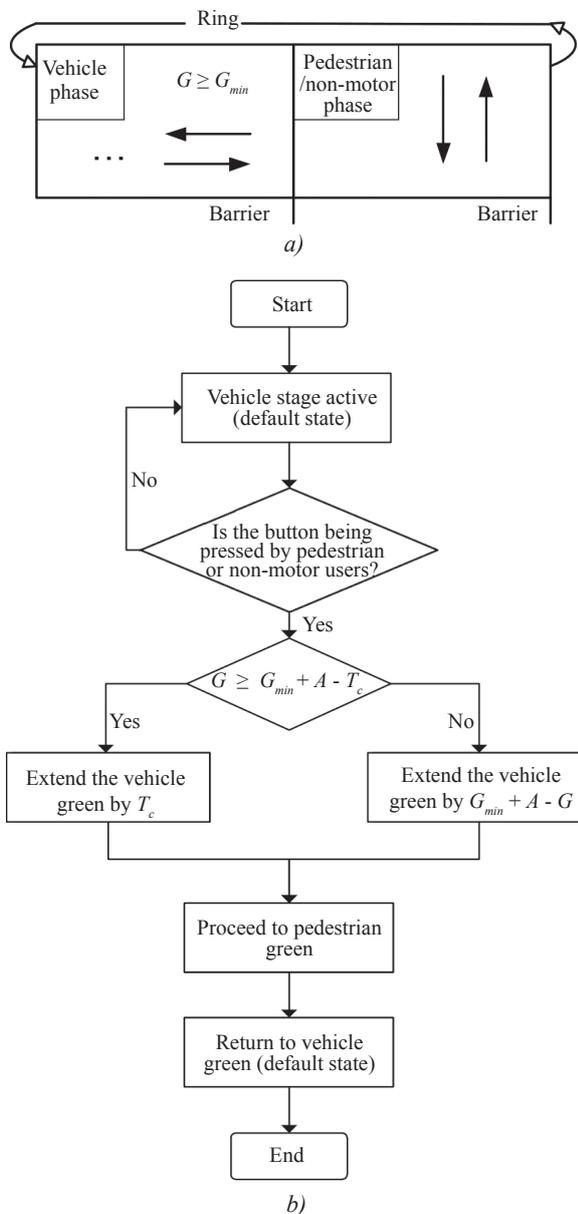


Figure 7 –The phase scheme of the selected MBC (a) and the procedure of VAP program (b)

In *Figure 7*,  $G$  is the duration of vehicle green when the signal is activated by a pedestrian or non-motor user (s);  $G_{min}$  is the minimum duration of vehicle green between two consecutive activations of pedestrians (s);  $A$  is the duration of vehicle amber time (s) and is set to 3 seconds in this paper;  $T_c$  is the minimum vehicle clearance time (s) and is set to 10 seconds green time and 3 seconds amber time.

Vehicle volume data in *Table 1* and traffic user speed data in *Figure 5* were used as the input of all models. As for the total volume of pedestrians and non-motor users, it was set from 20 to 180 with the increment of 20 (e.g. 20 pedestrians/non-motor users, 40,..., until 180). The selection of the increment mainly considers the number of models to be developed and the reliability of experimental results. Under each volume, we set the proportion of pedestrians from 20% to 100% with the increment of 10% (e.g. 20% pedestrians with 80% non-motor users, 30% pedestrians with 70% non-motor users,..., until 100% pedestrians). Pedestrian proportion under 20% is not considered, as such combination rarely occurs in reality.

For each combination under each volume, three experimental schemes are considered: (I) no UD strategy is used, i.e., no upstream push button is placed; (II) UD strategy is only applied to pedestrians, i.e., upstream push buttons are only placed on pedestrian crossing paths; (III) UD strategy is applied to both pedestrians and non-motor users, i.e., upstream push buttons are placed on crossing paths of both pedestrian and non-motor users. With these considerations, a total of  $9 \times 9 \times 3 = 243$  models were developed to test the effectiveness of the UD strategy under mixed traffic circumstances.

In each model, a detector with a width of 0 m was set to model the pedestrian push button. The VAP module was employed to code the control scheme of the example MBC. To make the model closer to reality, the last 8 seconds of pedestrian green signal was set to prohibit pedestrians from crossing the street, as 8 seconds is usually not enough for pedestrians to go through the whole crosswalk. Conflict areas were also set up to deal with pedestrian-vehicle conflict in case that the slow walkers are trapped on the street. Delay was chosen as the measure of effectiveness (MOE) to evaluate the system performance of the MBC. The delay value is measured by seconds/pedestrian or seconds/non-motor user.

However, some behaviours of pedestrians and non-motor users are not included in the model, such as non-compliance of pedestrians with the signal, deceleration of the non-motor users at the position of the upstream push button. These can be considered as limitations of our methodology and need to be overcome in further study.

## 4.2 Determination of signal control parameters

There are primarily two control parameters for a semi-actuated MBC. One is pedestrian crossing time, and the other is minimum vehicle green. Pedestrian crossing time  $P_c$  (s) can be calculated by using Equation 1 [23]:

$$P_c = 7 + L_c/v_p \quad (1)$$

where the number “7” is the pedestrian perception of signal indication and curb departure time (s);  $L_c$  is the length of the crosswalk (m);  $v_p$  is the 15th-percentile pedestrian crossing speed (m/s).

The purpose of introducing minimum vehicle green ( $G_{min}$ ) is to alleviate the impact of too frequent calls from pedestrians, especially in peak hour when the vehicular volume is high.  $G_{min}$  is similar to the phase green time at an intersection under fixed-time signal control. The determination of  $G_{min}$  is to deal with the trade-off between the efficiency of vehicles and pedestrians. As  $G_{min}$  increases, the vehicles become more efficient while more delays are added to pedestrians. A natural thought is to find an optimal  $G_{min}$  to minimise the overall delay of all traffic users. However, the situation is different at the MBC because there are far more vehicles than pedestrians/non-motor users, so overall delay minimisation will be biased towards vehicles and lead to unreasonable results. Therefore, this paper uses another objective to find an optimal  $G_{min}$ : minimisation of the delay difference between pedestrians/non-motor users and vehicles. (i.e., an objective that mainly deals with the equity of traffic users).

To simplify the problem, the determination of  $G_{min}$  was based on 100% pedestrian flow and experimental scheme without the UD strategy (as described in section “Model input”). For each pedestrian volume, we set  $G_{min}$  from 0 to 30 seconds with the increment of 5 seconds (e.g. 0s, 5s, 10s, ..., until 30s). For each volume under each  $G_{min}$ , we ran the simulation model under 5 different random seeds to obtain the delays of pedestrians and

vehicles. Then the average of delay was calculated to find the optimal  $G_{min}$  that minimises the delay difference between pedestrians and vehicles. The results are shown in Figure 8.

In Figure 8, the optimal value of  $G_{min}$  for each pedestrian volume is marked with a circle. These values are then applied to the simulation models for subsequent experiments.

## 4.3 Statistical approaches

Two statistical methods were used to interpret the simulation results: paired T-test and ANOVA (analysis of variance). Paired T-test is applicable for the situation where data from the experimental and control group are in the form of matched pairs [24]. In this way, the entire statistical analysis is done directly on the differences. The statistics ( $t$ ) of the paired T-test can be calculated through Equation 2:

$$t = \frac{D}{s_d/\sqrt{n}} \quad (2)$$

where  $D$  is the difference in sample means;  $s_d$  is the standard deviation of sample differences; and  $n$  is the number of observations. A  $p$ -value (or calculated probability) can be obtained from the  $t$ -distribution table. Under a significance level of 0.05, a  $p$ -value less than 0.05 suggests that the mean values are significantly different [25].

Analysis of variance (ANOVA) is devised originally to test the differences between several groups of treatments, thus avoiding the problem of making multiple comparisons between the group means using T-tests [26]. One-way ANOVA and two-way ANOVA are two most commonly used analysis methods. In the two-way ANOVA, experiments are done and observations are obtained under two factors. One factor is usually named treatment group and the other is block. Assume that only one experiment is made under each treatment group and block. The null hypothesis ( $H_0$ ) can be made first that the two factors have no effect on the experimental results. Then the sums of squares from different sources can be calculated through the observations. After that, mean squares and  $F$ -value can be calculated according to sums of squares and degrees of freedom. The statistical measurements of the two-way ANOVA are shown in Table 3:

In Table 3,  $x_{ij}$  is the observed value under group  $i$  and block  $j$ ;  $\bar{x}_j$  is the mean value for block  $j$ ;  $\bar{x}_i$  is the mean value for group  $i$ ;  $\bar{\bar{x}}$  is the overall mean of all the observations;  $SST$ ,  $SSG$ ,  $SSB$ ,  $SSE$  stand

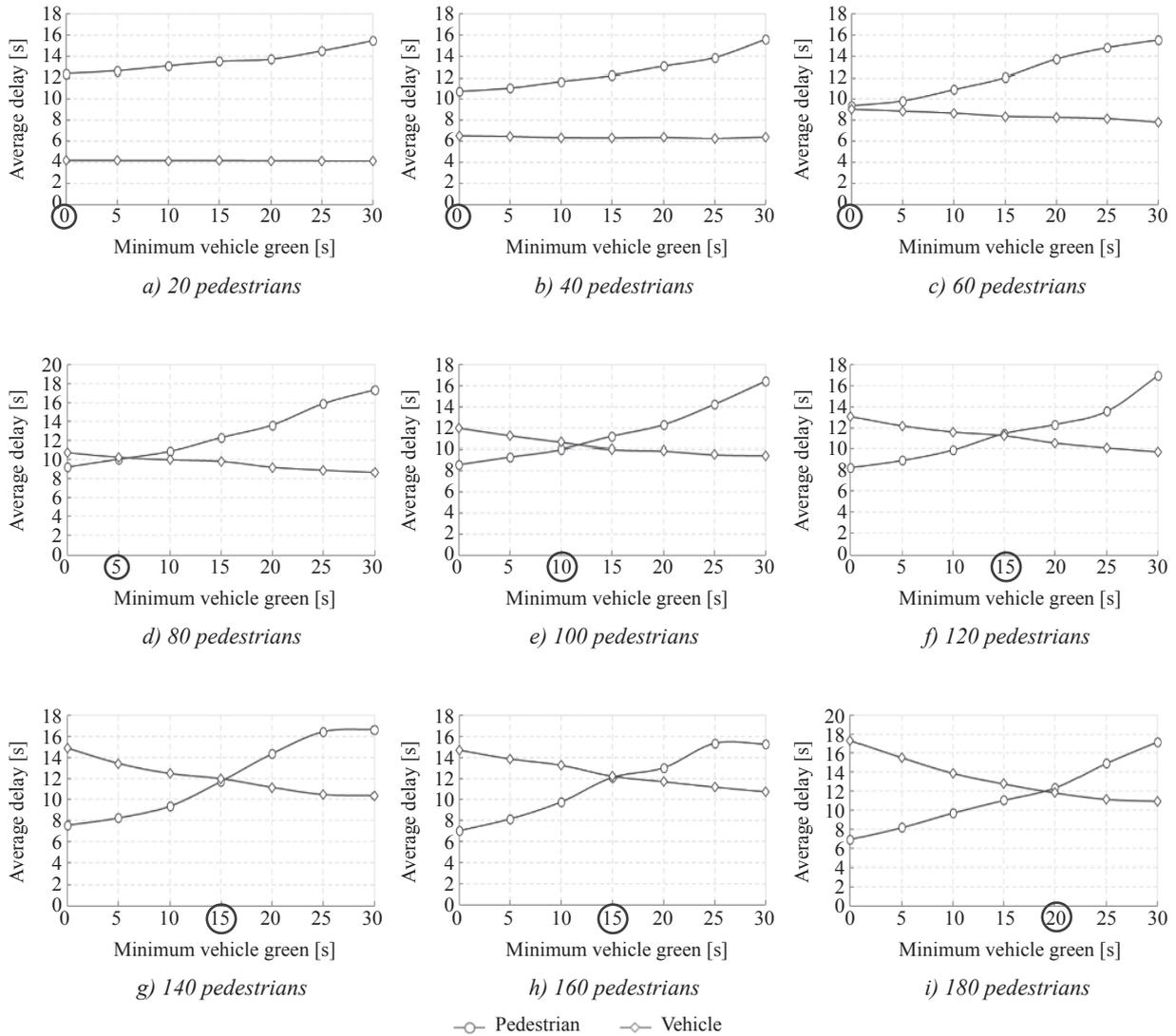


Figure 8 – The optimal minimum vehicle green for each pedestrian volume

Table 3 – The statistical measurements of the two-way ANOVA

Source of variation	Sums of squares	Degree of freedom	Mean squares	F ratio
Between groups	$SSG = \sum_{i=1}^g b(\bar{x}_i - \bar{x})^2$	$g-1$	$MSG = SSG/(g-1)$	$F_G = MSG/MSE$
Between blocks	$SSB = \sum_{j=1}^b b(\bar{x}_j - \bar{x})^2$	$b-1$	$MSB = SSB/(b-1)$	$F_B = MSB/MSE$
Error	$SSE = SST - SSG - SSB$	$(g-1) \cdot (b-1)$	$MSE = SSE/[(b-1)(g-1)]$	/
Total	$SST = \sum_{i=1}^b \sum_{j=1}^g (x_{ij} - \bar{x})^2$	$g \cdot b - 1$	/	/

for sums of squares of total deviations, between treatment groups, between blocks, and of random error, respectively;  $g$  and  $b$  are the number of treatment groups and blocks, respectively;  $MSG$ ,  $MSB$ ,  $MSE$  stand for mean squares between treatment groups, between blocks and of random error, re-

spectively;  $F_G$ ,  $F_B$  are  $F$ -values for the group and block, respectively.  $F_G$ ,  $F_B$  are then compared with  $F_{\alpha}(g-1, (g-1)(b-1))$  and  $F_{\alpha}(b-1, (g-1)(b-1))$  respectively under certain significance level  $\alpha$  (usually 0.05) to find out whether the two factors have effects on the experimental results.

### 5. RESULTS AND DISCUSSION

In this section, all the models were simulated under 10 different random seeds to obtain the delays of pedestrians and non-motor users. The random seeds were introduced to overcome the stochastic characteristics of traffic user. The delay results were then arranged by the volume, proportion, and experimental schemes described in Section “Model input”. After that, the paired T-test was conducted to explore the effectiveness of the UD strategy under each volume and proportion. The results are shown in Tables 4–6.

In Tables 4–6, *p*-values less than 0.05 are shown in italics. Table 4 shows the T-test results between experimental schemes I (no UD strategy is used) and II (UD strategy is applied to pedestrians only). Table 5 shows the T-test results between experimen-

tal schemes I and II (UD strategy is applied to both pedestrians and non-motor users). Table 6 shows the T-test results between experimental schemes II and III. Next, *p*-values less than 0.05 are replaced with “1”, otherwise they are replaced with “0”. This will form three new tables with all elements 0 or 1. Two-way ANOVA was then performed on these new tables. The results are shown in Table 7.

The first two parts of Table 7 show that whether the T-test is conducted between schemes I and II, or between I and III (i.e., whether the non-motor users use the upstream button or not), the *p*-value from block or volume factor is far less than 0.05, while that from the group or proportion factor is different. This indicates that the total volume of pedestrians and non-motor users has a significant impact on the effectiveness of the UD strategy, while the

Table 4 – Paired T-test results between experimental schemes I and II

Proportion	Volume [ped/h] or [veh/h]								
	20	40	60	80	100	120	140	160	180
100%, 0%*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0009	0.0003	0.1447	0.1529
90%, 10%	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	0.0027	0.0132	0.0317	0.0617
80%, 20%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.2883	0.0132	0.1069	0.0100
70%, 30%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0047	0.2955	0.0081	0.4804
60%, 40%	<0.0001	<0.0001	<0.0001	0.0001	0.0002	0.0012	0.0006	0.1681	0.1375
50%, 50%	<0.0001	<0.0001	<0.0001	0.0003	0.0006	0.2025	0.0038	0.0933	0.4354
40%, 60%	<0.0001	<0.0001	<0.0001	0.0001	0.0025	0.0107	0.0065	0.2671	0.2837
30%, 70%	<0.0001	<0.0001	<0.0001	<0.0001	0.0308	0.0001	0.4668	0.0004	0.0476
20%, 80%	0.0025	<0.0001	<0.0001	0.0005	0.3951	0.0353	0.0653	0.1155	0.1122

\*The first number (100%) is the proportion of pedestrians, the second (0%) is the proportion of non-motor users, and so forth.

Table 5 – Paired T-test results between experimental schemes I and III

Proportion	Volume [ped/h] or [veh/h]								
	20	40	60	80	100	120	140	160	180
100%, 0%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0009	0.0003	0.1447	0.1529
90%, 10%	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	0.0020	0.0306	0.0413	0.0577
80%, 20%	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.2140	0.0199	0.0416	0.0156
70%, 30%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0058	0.1322	0.0702	0.4245
60%, 40%	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0366	<0.0001	0.2118	0.1693
50%, 50%	<0.0001	<0.0001	<0.0001	<0.0001	0.0008	0.0376	0.0055	0.1659	0.4126
40%, 60%	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0018	0.0002	0.4802	0.2288
30%, 70%	<0.0001	<0.0001	<0.0001	<0.0001	0.0094	0.0011	0.0375	0.0090	0.1326
20%, 80%	<0.0001	<0.0001	<0.0001	<0.0001	0.0011	0.0012	0.0114	0.0554	0.0315

Table 6 – Paired T-test results between experimental schemes II and III

Proportion	Volume [ped/h] or [veh/h]								
	20	40	60	80	100	120	140	160	180
90%, 10%	0.0045	0.0017	0.0936	0.0387	0.0434	0.0471	0.2405	0.1718	0.0067
80%, 20%	0.0013	0.0008	0.0006	0.1503	0.1288	0.1590	0.4301	0.1499	0.1997
70%, 30%	0.0001	<0.0001	0.0365	0.0005	0.3026	0.4198	0.0436	0.4049	0.2018
60%, 40%	0.0002	0.0217	<0.0001	0.0035	0.0071	0.4725	0.0042	0.3707	0.3864
50%, 50%	<0.0001	<0.0001	0.0004	<0.0001	0.1870	0.0952	0.4072	0.1438	0.1130
40%, 60%	<0.0001	<0.0001	<0.0001	0.0003	0.0016	0.1520	0.0194	0.2566	0.4011
30%, 70%	<0.0001	<0.0005	0.0001	<0.0001	0.0131	0.0274	0.0014	0.1548	0.4828
20%, 80%	0.0233	<0.0001	<0.0001	0.0001	0.0315	0.0019	0.0448	0.3425	0.0761

Table 7 – The statistical measurements of the two-way ANOVA

Source of variation	Sums of squares	Degree of freedom	Mean squares	F ratio	p-value
T-test results between experimental schemes I and II					
Between groups (Proportion)	0.7654	8	0.0957	0.8464	0.5658
Between blocks (Volume)	6.5432	8	0.8179	7.2355	<0.0001
Error	7.2346	64	0.1130	/	/
Total	14.5432	80	/	/	/
T-test results between experimental schemes I and III					
Between groups (Proportion)	0.4444	8	0.0556	0.7273	0.6669
Between blocks (Volume)	6.8889	8	0.8611	11.2727	<0.0001
Error	4.8889	64	0.0764	/	/
Total	12.2222	80	/	/	/
T-test results between experimental schemes II and III					
Between groups (Proportion)	1.5556	7	0.2222	1.8589	0.0939
Between blocks (Volume)	8.8611	8	1.1076	9.2656	<0.0001
Error	6.6944	56	0.1195	/	/
Total	17.1111	71	/	/	/

pedestrian proportion, or the combination pattern of pedestrians and non-motor users, does not. When checking Tables 4 and 5, we can find that the results of ANOVA are more affected by the groups with high volumes, as nearly all the *p*-values are less than 0.05 under the volumes less than or equal to 100.

The third part of Table 7 shows that the total volume has a significant impact on the different applications of the UD strategy. However, when checking Table 6, we can find that the number of *p*-values above 0.05 is greater than that in Tables 4 and 5, which indicates that the impact of the volume factor on the category of the UD strategy is not as great as that on the effectiveness of the UD strategy.

The average delays of pedestrians and non-motor users were also calculated in experimental schemes II and III. The results are shown in Tables 8 and 9. Then two-way ANOVA was performed on these two new tables. The results are shown in Table 10.

Table 8 shows that when the total volume of pedestrians and non-motor users is below or equal to 100, the average delay increases as the proportion of non-motor users becomes higher, while the delay displays little relationship with the proportion when the volume is above 100. Table 9 shows a similar pattern except that the volume threshold changes to 80. When the total volume is above the threshold, the difference between the delay results under scheme

Table 8 – The delay(s) results in experimental scheme II

Proportion	Volume [ped/h] or [veh/h]								
	20	40	60	80	100	120	140	160	180
100%, 0%	3.98	4.13	4.82	5.51	7.39	9.85	9.94	11.36	12.45
90%, 10%	3.65	4.65	5.21	6.19	7.48	10.69	10.03	10.23	12.5
80%, 20%	5.16	4.87	5.38	5.98	7.91	11.01	10.00	10.45	11.99
70%, 30%	5.31	5.37	5.64	6.81	8.25	10.16	10.51	10.08	12.37
60%, 40%	5.81	5.78	5.77	7.19	8.47	9.62	9.75	10.23	12.40
50%, 50%	6.63	7.17	6.34	7.38	7.81	10.06	9.73	10.30	12.24
40%, 60%	7.64	6.85	6.73	7.40	8.49	10.30	9.77	10.12	12.14
30%, 70%	8.87	7.63	7.30	7.63	8.32	9.19	10.50	9.80	11.97
20%, 80%	8.75	8.23	7.94	8.27	9.32	10.40	9.93	10.14	11.88

Table 9 – The delay(s) results in experimental scheme III

Proportion	Volume [ped/h] or [veh/h]								
	20	40	60	80	100	120	140	160	180
100%, 0%	3.98	4.13	4.82	5.51	7.39	9.85	9.94	11.36	12.45
90%, 10%	3.28	4.33	5.09	5.95	7.4	10.5	10.19	10.31	10.31
80%, 20%	4.48	4.35	4.9	5.85	7.74	10.88	9.98	10.29	12.07
70%, 30%	4.29	4.72	5.31	6.22	8.06	10.21	10.21	10.16	12.46
60%, 40%	4.6	5.25	5.02	6.65	8.02	9.6	9.31	10.38	12.31
50%, 50%	5.05	5.62	5.25	6.61	7.58	9.74	9.77	10.46	12.08
40%, 60%	5.72	5.33	5.5	6.49	7.74	10.02	9.16	9.85	12.08
30%, 70%	6.76	6.2	6.26	6.28	7.84	8.59	9.87	9.53	11.98
20%, 80%	7.18	6.48	5.86	7.14	7.87	9.37	9.47	10.05	11.38

Table 10 – The statistical measurements of the delay results

Source of variation	Sums of squares	Degree of freedom	Mean squares	F ratio	p-value
Delay results from experimental scheme II					
Between groups (Proportion)	22.8620	8	2.8577	3.9865	0.0007
Between blocks (Volume)	372.8471	8	46.6059	65.0137	<0.0001
Error	45.8792	64	0.7168625	/	/
Total	441.5883	80	/	/	/
Delay results from experimental scheme III					
Between groups (Proportion)	4.1201	8	0.5150	1.1220	0.3608
Between blocks (Volume)	484.4455	8	60.5557	131.9298	<0.0001
Error	29.3760	64	0.4590	/	/
Total	517.9416	80	/	/	/

II and scheme III become extremely small. That is because as the volume grows higher, the semi-actuated control mode becomes less effective, and the signal is getting closer to one with a fixed cycle length.

From Table 10, we can see that for scheme II, *p*-values from both row and column factors are far less than 0.05, which indicates that both the volume and proportion have significant effects on the average delay when the UD strategy is applied to

pedestrians only. For scheme III, the  $p$ -value from column or group factor is far less than 0.05, while that from row or block factor is different. This indicates that when the UD strategy is applied both to pedestrians and non-motor users, the volume has a significant effect on the average delay, while the proportion does not. This could explain why applying the UD strategy to both pedestrians and non-motor users is more likely to treat them as a whole, so that the impact of proportion on the delay is not as obvious as applying the UD strategy to only pedestrians.

These results indicate that when all the non-motor users utilise the upstream push button to cross the road, the average delay can be further reduced compared to the situation where only pedestrians use it. Therefore, when the UD strategy is implemented in the field, it is also necessary to consider the convenience for non-motor vehicles to use the upstream button.

## 6. CONCLUSIONS

As the traffic is becoming more and more congested, it is necessary to encourage more people to choose walking within reasonable travel distance. The proper design of pedestrian facilities is a key factor to guide people to change the trip mode. Mid-block crosswalk (MBC), as a widely used pedestrian facility, is mainly installed between two adjacent intersections to improve the accessibility to pedestrians. However, pedestrians always experience long waiting time at the MBC which makes walking frustrating. To address this problem, upstream detection (UD) strategy is proposed by previous studies to reduce pedestrian delay. The limitation of these studies is the assumption of pure pedestrian flow.

This paper further applied the UD strategy to MBC in a mixed traffic circumstance where the crosswalk serves both pedestrians and non-motor users. The purpose of this study is to test if the UD strategy is still effective in such a circumstance. To achieve this, data was collected from an MBC in the city of Nanjing, China. VISSIM software and its add-on module Vehicle Actuated Programming (VAP) were utilised to develop simulation models considering the volume and composition of pedestrians and non-motor users. Models were simulated under different experimental schemes and random seeds. T-test and analysis of variance (ANOVA) were used to interpret the simulation results. The

main conclusions are that although there is a speed difference between pedestrians and non-motor users, the UD strategy is still effective at the MBC with a mixed traffic circumstance despite the proportion of non-motor users. Therefore, the UD strategy can still be implemented at the MBC that serves both pedestrians and non-motor users. However, as the proportion of non-motor users becomes higher, the average delay of pedestrians and non-motor users will increase compared to pure pedestrian flow. This is more obvious when only pedestrians use the upstream push button.

Due to limited time and energy, this paper does not explore the factor of crossing behaviour. In reality, a certain proportion of pedestrians and non-motor users may cross the road illegally (e.g. violate the signal, go outside of the crosswalk), which makes the problem more complicated. Further studies can apply other theories and tools, such as social force model and Anylogic software, to deal with more crossing behaviours and the interaction between crosswalk users to get more precise results.

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杨震<sup>1</sup> Email: zyang\_2016@163.com

马健霄<sup>1</sup> Email: majx@njfu.edu.cn

王宝杰<sup>2</sup> Email: wangbj2@163.com

闫星臣<sup>1</sup> Email: xingchenyan.acad@gmail.com

<sup>1</sup> 南京林业大学汽车与交通工程学院,  
江苏省南京市龙蟠路159号, 210037

<sup>2</sup> 长安大学运输工程学院,  
陕西省西安市南二环路中段, 710064

混合流交通环境下行人上游检测策略的应用分析

摘要

步行是一种对环境友好的出行方式, 有助于缓解汽车造成的拥堵。合理设计行人交通设施, 提高步行的效率和安全性, 可以鼓励更多的人选择步行。为减少路段平面过街横道处的行人等待时间, 此前的研究提出了上游检测(UD)策略。本文将UD策略应用于混合交通环境下, 同时服务于行人和非机动车的平面过街横道; 通过采集中国南京市一处平面过街横道的交通数据, 使用VISSIM软件及其附加的车辆感应控制(VAP)模块构建了仿真模型。模型根据行

人和非机动车的流量和比例进行分类，并在不同的试验方案下进行仿真模拟，以探讨混合交通环境下UD策略的有效性。仿真结果采用 $t$ 检验和方差分析(ANOVA)进行解释。本文的主要结论是：在混合交通条件下，尽管存在着非机动车，但UD策略仍然有效。然而，和纯行人流条件相比，随着非机动车比例的增加，行人和非机动车的平均延误将会升高。

#### 关键词

路段平面过街横道；上游检测；行人；非机动车；VISSIM；延误

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