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CALIBRATION OF PEDESTRIAN SIMULATION MODEL FOR SIGNALIZED CROSSWALK IN HONG KONG

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Abstract: This paper presents the calibration of a pedestrian simulation model for simulating pedestrian movements at a selected signalized crosswalk in Hong Kong. This model is able to estimate the variations of walking speed particularly under conditions with bi-directional pedestrian flows. A simulation software package, Service Model, was adopted to develop the pedestrian simulation model for the selected signalized crosswalk. The simulation results gained in this study includes pedestrian flows on the selected crosswalk, walking times on the different measurement section of the crosswalk and waiting times at the waiting areas. A comparison was made between the simulated results and the observed data. It is found that the comparison results were satisfactory. Therefore, it is believed that the calibrated pedestrian simulation model for signalized crosswalk can be used for improvement of the pedestrian environment particularly under conditions of heavy opposing pedestrian flows. The model can be applied to assess the effects of bi-directional pedestrian flows and to evaluate the benefits of this effects in practice.

Key Words: Pedestrian Delay, Simulation, Signalized Crosswalk

1. INTRODUCTION

Better planning for pedestrians, promoted by Planning Department (PD, 2001) of the Hong Kong Special Administrative Region (SAR) is one of the means designed to enhance the living environment quality of people in urban areas. Better planning for pedestrians helps to provide better linkage among various transport modes, enhances land use activities, improves pedestrian circulation, the quality of walking environments and minimizes conflict between pedestrians and vehicles at the signalized crosswalks. Therefore, understanding pedestrian walking behavior in order to prioritise pedestrian needs, is of prime importance in the study of planning and design of the pedestrian facilities. Among various pedestrian facilities, signalized crosswalks are one of the most complex facilities, with high risk for pedestrians in congested urban areas, since pedestrians and vehicles share the same road space but different time intervals, in accordance with the signal cycles. The complexity of the traffic signals often creates problems since the provision and allocation of crossing time for pedestrians is usually apportioned from conflicting vehicular traffic flows. Therefore, the impact of the duration of the pedestrian green and flashing green times on pedestrians is thus a worthwhile study endeavor. However, predicting pedestrian delays at signalized crosswalks requires a sophisticated pedestrian simulation model particularly for environments with a heavy opposing pedestrian flow.

Owing to the high density populated development, most urban areas in Hong Kong are characterized by a high level of conflicting pedestrian-vehicle movements and traffic congestion as well as overcrowded pedestrian facilities. To cope with these ever-growing traffic problems, the Hong Kong SAR Government (Transport and Traffic Survey Division, 1985) recognized the necessity to study pedestrian flow characteristics in order to develop a simulation model for future planning. In response, Lam et al. (1995) conducted a comprehensive study on the pedestrian flow characteristics of Hong Kong people. Later, Lam and Cheung (2000) summarized the findings of pedestrian flow characteristics for different types of walking facilities in Hong Kong. Lam et al. (2002) studied the pedestrian walking speed-flow relationships at signalized crosswalks under different land uses. In particular, they investigated the effects of bi-directional pedestrian flow on walking speed at capacity and effective capacity on Hong Kong signalized crosswalk. They also pointed out that a further study on the development of a pedestrian simulation model was required.

In Hong Kong, the current practice in signalized intersection design to assume the pedestrian walking speed to be constant (i.e. 1.2 m/sec) and fixed regardless of the prevailing pedestrian flow conditions. In view of this assumption, it is considered that the current approach is over-simplified for pedestrians may not have adequate time to cross a signalized crossing particularly when the opposing pedestrian flow is high and the pedestrian flows on the crosswalk approaches to its capacity. It is thus felt that for pedestrian safety, the assessment/design of a signalized crosswalk should be based on its capacity but with the consideration of the walking speed under different flow ratios.

A model for forecasting pedestrian flows and walking times in congested urban areas would help to identify potential locations of new pedestrian facilities such as signalized crosswalks. Forecasting pedestrian flows and delays in congested urban areas requires a sophisticated pedestrian simulation model such as the PEDROUTE package (Halcrow Fox and Associates, 1994 & Buckman and Leather, 1994) developed for the London Underground stations. In recent years, researchers, such as Blue and Adler (1998 & 2001) focused on Cellular Automata (CA) microsimulation. CA microsimulation is characterized as an artificial life approach to simulate pedestrian behaviors and movements. Such advancement of techniques in transport modeling has contributed to the development of pedestrian simulation models. However, pedestrian walking behavior should not be over-looked as related parameters are crucial.

This paper will be presented in the following manner. First, this paper addresses issues associated with the need of pedestrian simulation model for signalized crosswalk in Hong Kong. Following this, a description of the model development is provided. The model formulation is then considered with a presentation of data collection from the observation survey. This paper then reports the data extracted and analyzed so as to calibrate the model parameters. Finally, the simulated results are compared with the observed data.

2. MODEL DEVELOPMENT

2.1. The Pedestrian Simulation (PS) Model

The objective of the PS model is to simulate the pedestrian movements at signalized crosswalk in Hong Kong. This PS model is also capable to estimate the pedestrian flows and walking times on the crosswalk together with their variations. Therefore, a specific pedestrian signalized crosswalk was selected for model calibration. This chosen signalized crosswalk is one of the busiest in Hong Kong. The physical characteristics, such as length, width and signal cycle time of this crosswalk are indicated in Figure 1. The length and width of the crosswalk are 18.2 m and 14.5 m respectively. The cycle length was 120 sec. The green and flashing green times were about 30 sec and 13 sec respectively. Moreover, the red time was 77 sec which included the all-red time (i.e. 2 sec). For pedestrian signal at crosswalk in Hong Kong, the sequence is red, green, flashing green and red. When the pedestrian steady red signal (red stationary man) is illuminated, pedestrian shall not cross or start to pass through the crosswalk. The pedestrian green signal (green walking man) when illuminated by a steady shall indicate that pedestrians can transverse the crosswalk. When the green signal is illuminated by an intermittent light (flashing green man) shall indicate that (i) to pedestrians who are already on the crosswalk that they should speed up to completely pass through the facility; and (ii) to pedestrians who are not on the crosswalk that they should not start to cross the facility.

Physical Characteristics

Width = 14.5 m
Length = 21.0 m

Signal Cycle Time (sec)

Pedestrian Green + Flashing Green = 43 sec
Pedestrian Red = 77 sec
Cycle Time = 120 sec

Figure 1. Physical Characteristics of the Selected Signalized Crosswalk

2.2. Experimental Site

Causeway Bay is one of the most popular shopping districts in Hong Kong (see Figure 2). It is flocked with crowds of people and heavy traffic throughout the day. Recently, the Hong Kong SAR Government proposed to implement a Pedestrianisation Scheme[1] and Pedestrian Priority Zone[2] in Causeway Bay in order to give pedestrians priority in the use of road space. The

Pedestrianisation Scheme incorporates a full-time pedestrian street (i.e. vehicular access is restricted to emergency services only throughout the day), a part-time pedestrian street (i.e. vehicular access is only allowed during specific periods) and a traffic claming street (i.e. footpaths are normally widened and low speed vehicular access is unrestricted). The Pedestrian Priority Zone in Causeway Bay involves planning for peripheral public transport interchanges, creating a new pedestrian corridor at the heart of the Pedestrian Priority Zone, minimizing pedestrian/vehicular conflict within the key area of heavy pedestrian usage, incorporating new underground railway station entrances and sustaining the activity areas. As the pedestrian movements within the study area are critical during the peak periods, an understanding or knowledge of peak hour pedestrian flow characteristics would help in the design and improvement of the pedestrian facilities in congested urban areas.

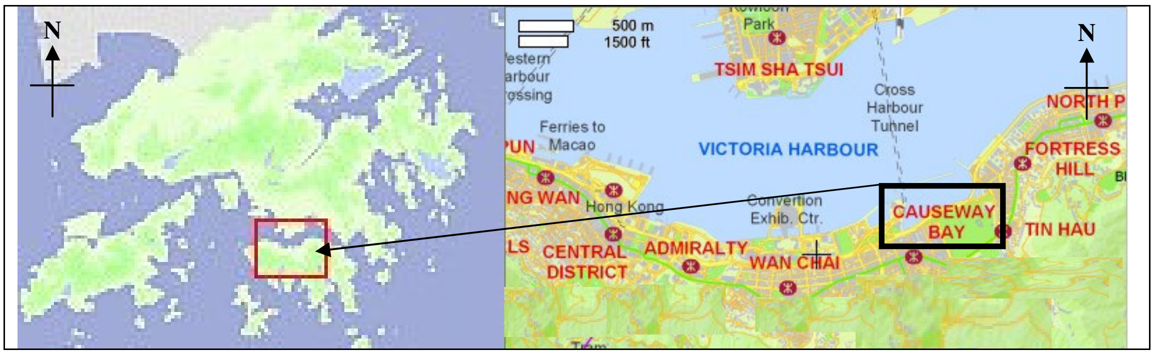

Figure 2 Location Map of Causeway Bay

2.3. The Service Model

The main aim of any simulation package is to model the characteristics and interaction of all the elements of a system as faithfully as possible in order to predict accurately what will happen if a situation is changed. Six simulation packages (Service Model, Automod II, PEDROUTE (Halcrow Fox and Associates, 1994), STEPS, Egress and Legion/Vegas) have been compared and reviewed by the Hong Kong Mass Transit Railway Corporation Limited (MTRCL, 1998). The approach and degree of details in modeling pedestrian movement behavior together with route choices under various situations were found to be the main differences in the 6 simulation packages.

The package, Service Model, developed by Promodel Corporation (2004) is used by the MTRCL to model the pedestrian movements in the underground stations (Lee and Lam, 2001). This model can accurately estimate the location pedestrian flows and path walking times within the station. The estimation error is proven to be only within 5 %. It is a window-based simulation tool for simulating and analyzing service systems. It provides flexibility and power for modeling any situations such as the provision of interface sub-routines for modeling

[1] information about Pedestrianisation Schemes can be found in "Pedestrianisation Schemes for Hong Kong" from the Transport Department internet homepage http://www.info.gov.hk/td/eng/transport/ped_index.html

[2] information about Pedestrian Priority Zone can be found in "Pedestrian Plan for Causeway Bay - Technical Note" from the Planning Department internet homepage http://www.info.gov.hk/planning/index_e.htm

pedestrian flow and facilities utilization. It also provides automatic error and consistency checking. Animated representation of the system is one of the main advantages of the Service Model. After a simulation run, it can automatically tabulate and plot the simulation results. The simulation environment provided by the Service Model is adequate to handle both normal and emergency situations. The model developer can completely control the approach, logic and degree of modeling detail in the Service Model so as to simulate the pedestrian flow and delay under normal situations and also chosen special events.

The layout of the chosen signalized crosswalk was built by using AutoCAD software and further incorporated into the Service Model. This layout is illustrated in Figure 3 and was incorporated into the PS model for graphic presentation. The chosen crosswalk was further divided into four main measurement sections and illustrated in Figure 3, namely: Waiting Area (N); Crosswalk Area (N); Crosswalk Area (S); and Waiting Area (S). Li et al. (2005) pointed out that walking directions might influence pedestrian delays. Therefore, in this study, pedestrians are divided into two categories: North Bound (NB) pedestrians, who encounter the west bound vehicle flow first; and South Bound (SB) pedestrians, who encounter the east bound vehicle flow first. There are three east bound traffic lanes while only one of which is west bound of the road. A tram-way is also located at the study area (see Figure 3).

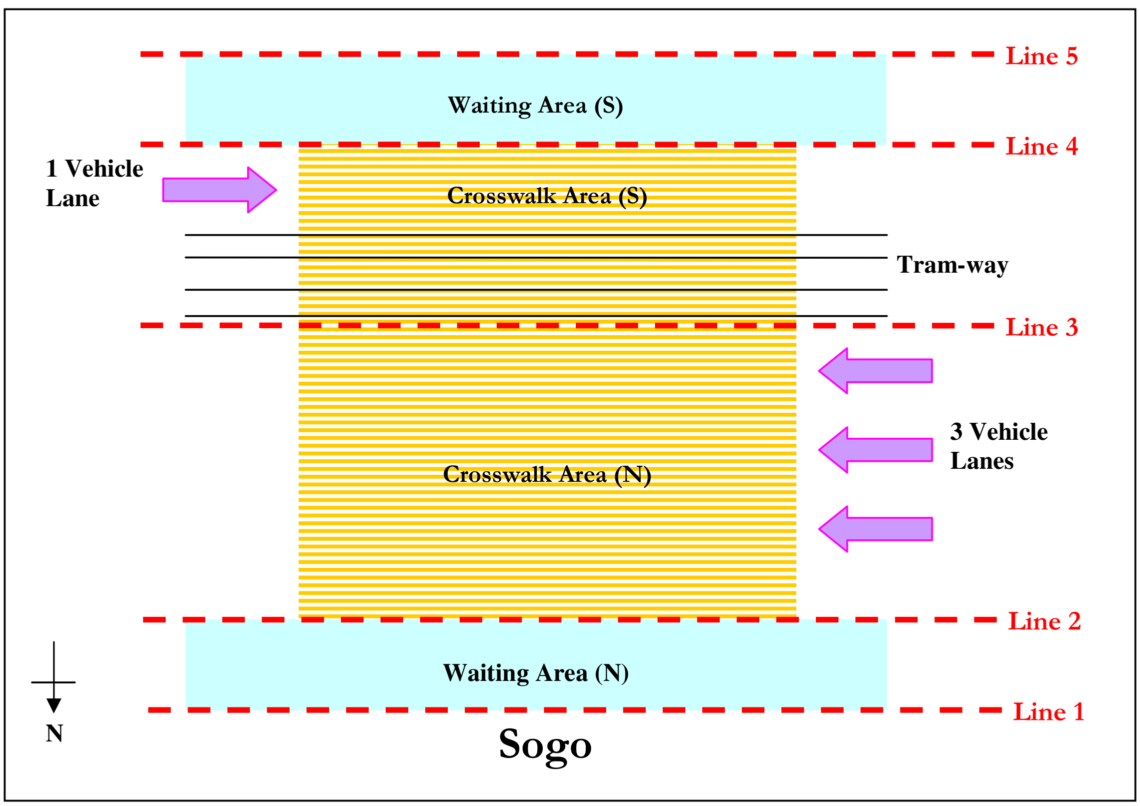

Figure 3. Layout of the Causeway Bay Signalized Crosswalk

The pedestrian speed-flow relationship of signalized crosswalks calibrated by Lam et al. (2002) was also incorporated into the PS model to estimate the pedestrian walking times and delays on the chosen crosswalk. The detailed formulation of the pedestrian walking time function is discussed later in this paper. The total simulation time for the model is 60 minutes.

Figure 4 shows the developed PS model for the selected Causeway Bay signalized crosswalk. The white dots represent the NB pedestrians, while the red dots represent the SB pedestrians. Each dot in Figure 4 illustrates one pedestrian movement within the study area.

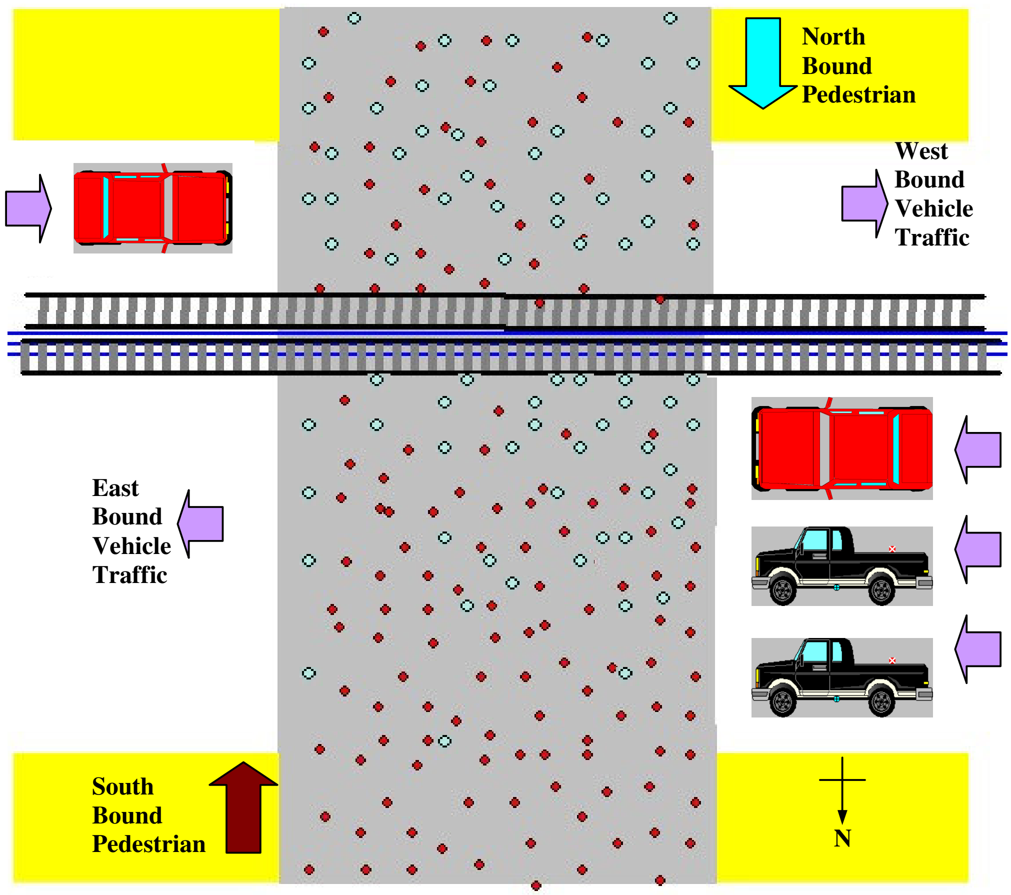

Figure 4. Pedestrian Simulation Model for Causeway Bay Signalized Crosswalk

3. THE MODEL FORMULATION

Pedestrian flows are inherently more complex than vehicular flows as the bi-directional flow effects are considered in pedestrian movements. The objective of this study is to develop an intuitively and empirically appealing pedestrian simulation model for signalized crosswalks. By incorporating the calibrated pedestrian walking time-flow relationship and the effects of bi-directional pedestrian flow, the model can simulate pedestrian movements and walking behaviors on signalized crosswalks, particularly when the pedestrian flow approaches its capacity and faces heavy opposing flows.

Blue and Alder (2001) pointed out that there were three fundamental elements of pedestrian movements that a bi-directional microscopic model should cater for:

a) Side stepping - the desire of a pedestrian to "switch-lanes" move laterally to either enable increased velocity or avoid head-on conflicts;
b) forward movement - the desired speed of the pedestrian and the placement of other

persons in the immediate neighborhood; and

c) Conflict mitigation - the manner in which pedestrians approaching each other from opposite directions manage to avoid a head-on collision or deadlock.

These pedestrian movements can be easily observed at a congested crosswalk. When the pedestrian flow on the crosswalk approaches its capacity and faces a heavy opposing flow, there is less freedom to choose a walking speed (forward movement). They will also shy away (or side stepping) from the opposing pedestrians so as to mitigate head-on conflicts (conflict mitigation).

Unlike the microsimulation rules used in CA, there are several built-in routing rules in the Service Model package. They are common rules for pedestrian routes such as:

a) "First Available" – pedestrians select the first location that has available capacity;
b) "Most Available" – pedestrians select the location that has the most available capacity;
c) "Random" – pedestrians select randomly among two or more available locations; and
d) "Probabilistic" – pedestrians select the location based on the probability specified.

In reality, pedestrians usually try to minimize their walking times when walking on a crosswalk. They like to select the first location that has available capacity. In view of this, the routing rule – "First Available" was selected in the PS model as the most realistic to simulate the pedestrian walking behavior. This routing rule causes the first location (with available capacity) listed in a block of routes to be selected. Pedestrians can change lanes only when an adjacent location has available capacity. For the step forward movement, a minimum distance of 0.5m is kept in the front so as to eliminate conflicts with the opposing pedestrian. If an empty location between two pedestrians is available, pedestrian who first enters the empty space has the occupancy right (as stated in the "First Available" rule) will be located in this location.

3.1. Pedestrian Stop/Cross Probability during Pedestrian Flashing Green Time

In Hong Kong, there are three phases of pedestrian signal: pedestrian green time, flashing green time and red time. Pedestrians are not allowed to walk thought the crosswalks during pedestrian red time, but allowed to transverse during pedestrian green time. When the pedestrians arrived during flashing green time, they are also not allowed to enter the crosswalks. However, for those who were already on the crosswalks, they are forced to speed up for safety reason.

From the observation results, the stop/cross probabilities when the pedestrians arrived during flashing green time were determined. The duration of the flashing green time is 13 sec. The trade-off between stop and cross decision is about half of the duration of pedestrian flashing green time (i.e. 6 sec) from the empirical data. It was found that majorities of the pedestrians will cross during the first 7 sec of flashing green time. However, it was worth noting that there are over 50% of pedestrians will not cross when they arrived during the last 6 sec of flashing green time. Therefore, 6 sec is selected for the stop/cross probability criteria. Two assumptions had been made. Firstly, it was assumed that all pedestrians will transverse the crosswalk once they arrived during pedestrian green time. Another assumption was that all pedestrians arriving during pedestrian red will not transverse the crosswalk until next pedestrian green.

4. DATA COLLECTION

An observation survey recorded by video was conducted at the selected Causeway Bay signalized crosswalk (Figure 1) during the evening peak hour on a typical Friday in November 2003. The evening peak hour 17:30-18:30 was chosen for the survey as it was found from the passenger data provided by MTRCL for Causeway Bay MTR station that the evening peak hour was the most congested period throughout a day. Data such as pedestrian arrival/departure patterns, pedestrian walking times at each measurement section and pedestrian waiting times/delays at each waiting area (Figure 4) were collected. The collected data was used to calibrate the simulation model.

A time-lapse photography technique, adopted in a number of previous studies (Cheung and Lam, 1997 & 1998; Lam and Cheung, 2000; Lam et al., 2002 & 2003) was used to collect pedestrian walking times and the corresponding pedestrian flows. The use of a video camera together with a lightweight tripod is necessary when the pedestrian flow at selected locations is significantly high and the pedestrian movements complex. In this survey, the video camera was used to record the high pedestrian flows and complex movements at the selected signalized crosswalk (see Figure 1) so as to minimize the on-site measurement errors. With the use of video recording equipment, information can be extracted from the video records in the laboratory with the aid of a computer.

5. DATA EXTRACTION

As described in Section 4, the walking times and the corresponding pedestrian flows were extracted from the video records in the laboratory with the assistance of a computer. Before data extraction, a time code with a precision of 0.04 sec was mapped onto the video images so as to enhance the measurement precision. A detailed description of the data extraction method can be found in Lam et al. (2003).

In Figure 3, five lines (locations) were selected for counting the pedestrian flows at the study area. The pedestrian arrival and departure patterns were extracted from the flow data collected at each line. The choice of survey locations for counting the flow within the signalized crosswalk was dependent on the variation of the pedestrian flows at these locations. Survey personnel were required to record the accumulated pedestrian flows at these chosen locations, by each pedestrian green (including pedestrian flashing green) and pedestrian red times during the survey period. As a result, pedestrian flows for each pedestrian cycle time at each of these locations were obtained for the evening peak hour.

For the data extraction of pedestrian walking and waiting times, one pedestrian was chosen during each cycle. The specific time (i.e. corresponding time display on the time code, see Figure 2) that the chosen pedestrian transverses each line (see Figure 3) was recorded. The pedestrian walking or waiting time periods at each section was based on that pedestrian's entry and exit times at each crosswalk measurement section. For example, pedestrian waiting time at Waiting Area (N) can be obtained if the entry time at Line 1 and the exit time at Line 2 are known. By considering the times that the chosen pedestrian transverses Line 3 (exit) and Line 2 (entry), for Crosswalk Area (N), his/her walking time at that section can be obtained.

6. DATA ANALYSIS

6.1. Pedestrian Walking Time-flow Relationship on Signalized Crosswalk

The relationship between pedestrian flows and walking times for Hong Kong signalized crosswalks with different land uses had previously been calibrated by Lam et al. (2002). The signalized crosswalks in their study were situated in commercial and shopping areas with/without a Light Rail Transit (LRT) station. The walking time function for crosswalks in shopping areas without an LRT station were chosen for incorporation in the PS model. The chosen pedestrian BPR (Bureau of Public Roads, 1964) function is given below:

$$t(v) = 0.7927 + 1.1192 \times \left(\frac{v}{78.5} \right)^{5.0365} \tag{1}$$

where:
$t(v)$ is the estimated walking time (seconds) at two-way pedestrian flow v;

This walking time-flow function for pedestrian was then transformed into a walking time-density function for signalized crosswalk facilities and incorporated into the developed PS model.

6.2. The Effects of Bi-directional Pedestrian Flow on Signalized Crosswalks

When pedestrians use a crosswalk with a heavy opposing pedestrian flow, they tends to shy away from that flows and have less freedom to choose their walking speeds. As a result, the effective capacity of the crosswalk and pedestrian walking speed is reduced, particularly in the minor flow direction. These effects are mainly due to the imbalance of pedestrian directional split (i.e. flow ratio) and particularly significant when the pedestrian flows are close to the capacity of the facility.

The pedestrian flow ratio is defined as:

$$Flow\ \ Ratio\ (r) = \frac{One - way\ \ flow}{Two - way\ \ flow} \tag{2}$$

Pedestrian flow is the number of pedestrians passing through a measurement section of a walking facility per meter width per minute. The direction with a higher pedestrian flow is defined as *Major flow* direction while the direction with lower pedestrian flow is defined as *Minor flow* direction. Therefore, the range of the flow ratio (r) is $0. < r < 0.5$ for the minor flow direction and $0.5 \le r \le 1.0$ for the major flow direction.

The relationship of the flow ratio against the effective capacity was calibrated by Lam et al. (2002) and is shown below:

For Effective Capacity,

$$C_{eff} = 61.67 + 59.34 \times r - 70.86 \times r^2 + 28.41 \times r^3 \tag{3}$$

where:
r is the flow ratio.

By incorporating the above function, the bi-directional flow effects on effective capacity can be considered in the developed model. During the simulation run, the walking speeds of the pedestrians would be reduced when walking on the crosswalk and facing heavily opposing flows under at-capacity flow condition. The effective capacity of the signalized crosswalk is also reduced, hence, affected by the density of the crosswalk.

7. RESULTS AND COMPARISONS

In order to examine the performance of the developed PS model, the simulated results were compared with the observed data including pedestrian flows and pedestrian walking/waiting times at each measurement section.

7.1. The Observed and Estimated Pedestrian Flows

The pedestrian flows extracted from the video records are summarized in Table 1. The measurement time period is from 17:30 to 18:30 on one of the Fridays on November 2003. The physical characteristics of the chosen site such as cycle time, pedestrian green and red times are found in Figure 1. In the selected evening peak hour, there should be 30 pedestrian signal cycles. However, only 28 cycles (Cycle Nos. 2 to 29) are shown in Table 1. Cycle Nos. 1 and 30 are excluded as the data for these two cycles is used for initialization of the developed PS model.

Table 1. The Observed and Estimated Pedestrian Flows at Each Cycle (Two-way)

Cycle No.	Observed Flow	Estimated Flow	% Difference	Cycle No.	Observed Flow	Estimated Flow	% Difference
2	253	288	14%	16	300	336	12%
3	270	316	17%	17	263	280	6%
4	242	212	-12%	18	276	312	13%
5	266	256	-4%	19	269	332	**23%**
6	244	256	5%	20	323	272	-16%
7	242	236	-2%	21	307	236	**-23%**
8	200	252	**26%**	22	272	276	1%
9	274	268	-2%	23	249	296	19%
10	291	248	-15%	24	271	232	-14%
11	248	276	11%	25	307	296	-4%
12	303	288	-5%	26	324	320	-1%
13	264	304	15%	27	412	408	-1%
14	292	288	-1%	28	***467***	***444***	-5%
15	265	276	4%	29	367	348	-5%

Notes: the percentage difference $= \frac{(estimated - observed)}{observed} \times 100\%$

: the bold type figures show the percentage difference over 20%

In Table 1, the pedestrian flows (two-way) estimated by the newly developed PS model are compared with the observed values for the 28 cycles. The percentage differences are also presented, ranging from -23 percent to +26 percent. However, majorities are within +/- 20 percent. The observed pedestrian flows were plotted against the simulated results as illustrated in Figure 5. The study results revealed that each data point represents a pair of observed (y-axis) and simulated (x-axis) pedestrian flows at each cycle. Therefore, there are 28 data points in Figure 5. It is worth noting that the results estimated by the developed PS model are close to the observed one.

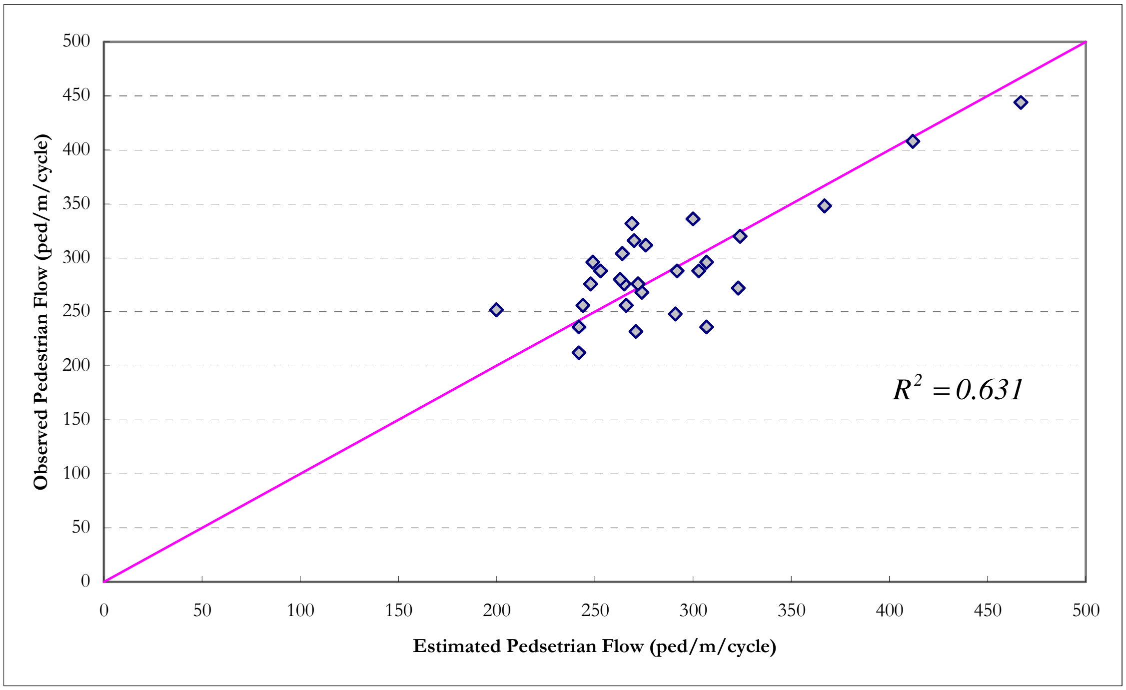

Figure 5. Observed Pedestrian Flows vs Results Simulated by the Model

7.2. The Observed and Estimated Pedestrian Walking Times

Pedestrians were chosen at each cycle to capture their walking times when transversing each measurement section. The observed mean pedestrian walking times at each measurement section are summarized in Table 2 together with the corresponding standard deviation. A total of 649 samples were extracted from the video records. The estimated population is recorded as 3876. It is also worth noting that the observed mean walking times at Waiting Area (S) in both directions are closed to those estimated. The observed standard deviations of its mean walking time are also closed to those estimated by the PS model. It is worth noting that the observed mean walking time at Waiting Area (S) – Southbound is much larger than the estimated results. This can partially be explained by the boundary of the study area (see Figures 2 and 3). The measurement area of Waiting Area (S) is bound by a restaurant and a construction site creating a bottleneck at the exit of the Waiting Area (S). Therefore, the observed walking time at Waiting Area (S) is much larger than the simulated one. This calls for a need for the boundary of the study area to be re-calibrated.

Table 2. The Observed and Estimated Walking Times at Each Measurement Section

Walking Times (North Bound)						
		Waiting Area (S)	**Crosswalk (S)**	**Crosswalk (N)**	**Waiting Area (N)**	**No. of Samples**
Observed	**Mean (sec/m)**	6.34	1.15	1.18	0.67	649
	S.D. (sec/m)	(5.58)	(0.24)	(0.27)	(0.17)	
Estimated	**Mean (sec/m)**	7.46	1.09	1.17	0.93	3876
	S.D. (sec/m)	(6.53)	(0.32)	(0.21)	(0.12)	
Walking Times (South Bound)						
		Waiting Area (N)	**Crosswalk (N)**	**Crosswalk (S)**	**Waiting Area (S)**	**No. of Samples**
Observed	**Mean (sec/m)**	4.17	1.18	1.03	***1.66***	656
	S.D. (sec/m)	(4.26)	(0.26)	(0.31)	(0.38)	
Estimated	**Mean (sec/m)**	5.25	1.17	1.04	***1.09***	4752
	S.D. (sec/m)	(4.43)	(0.36)	(0.16)	(0.23)	

Figure 6 shows the observed mean walking times vs results estimated by the PS model at Crosswalk (N) Northbound. Y-axis represents the observed mean walking time at each cycle while X-axis represents the corresponding estimated mean walking time. In Figure 6, the data point located above the diagonal line indicates that the observed results are larger than estimated results (i.e. underestimated). Their observed results for those below the diagonal line are smaller than estimated results (i.e. overestimated). It can be observed in Figure 6 that large numbers of data points are located above the diagonal line. It implies that the developed PS model underestimates the walking time at crosswalk (N) Northbound. This can partially explained by the fact that the observed walking times of the pedestrians may be increase owing due to heavy opposing flow. However, the developed model only considered the walking time function under uni-directional flow condition and the bi-directional pedestrian flow effects on walking speed at capacity and effective capacity. Therefore, further study is needed to generalize the walking time function under various flow ratios ranging from free-flow to at-capacity conditions.

Figure 7 shows the observed standard deviation of the mean walking times vs results estimated by the PS model at Waiting Area (N) in the Southbound. The Y-axis represents the observed standard deviation while the X-axis represents the corresponding estimated value. In Figure 7, data points located above the diagonal line indicate that the observed standard deviations are larger than estimated results (i.e. underestimated). For those below the diagonal line, the observed results are smaller than the estimated results (i.e. overestimated). This shows that the developed PS model can estimate both mean walking time and its variation arising from different congestion levels.

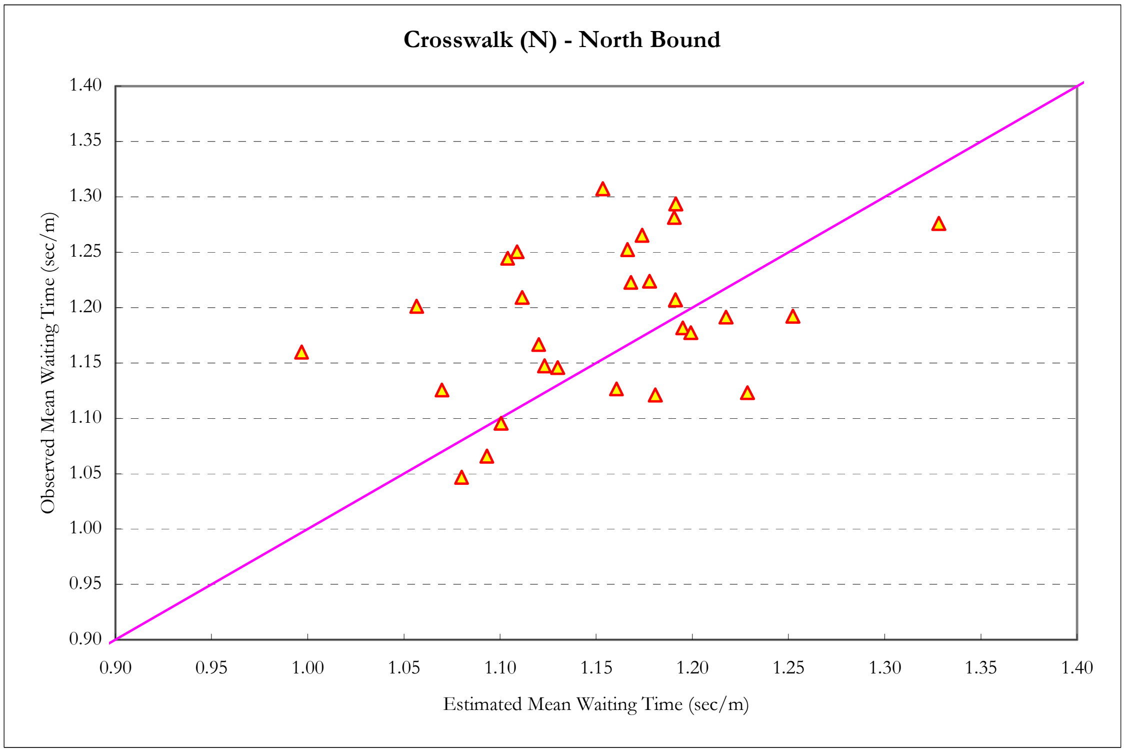

Figure 6. Observed vs Estimated Mean Walking Times

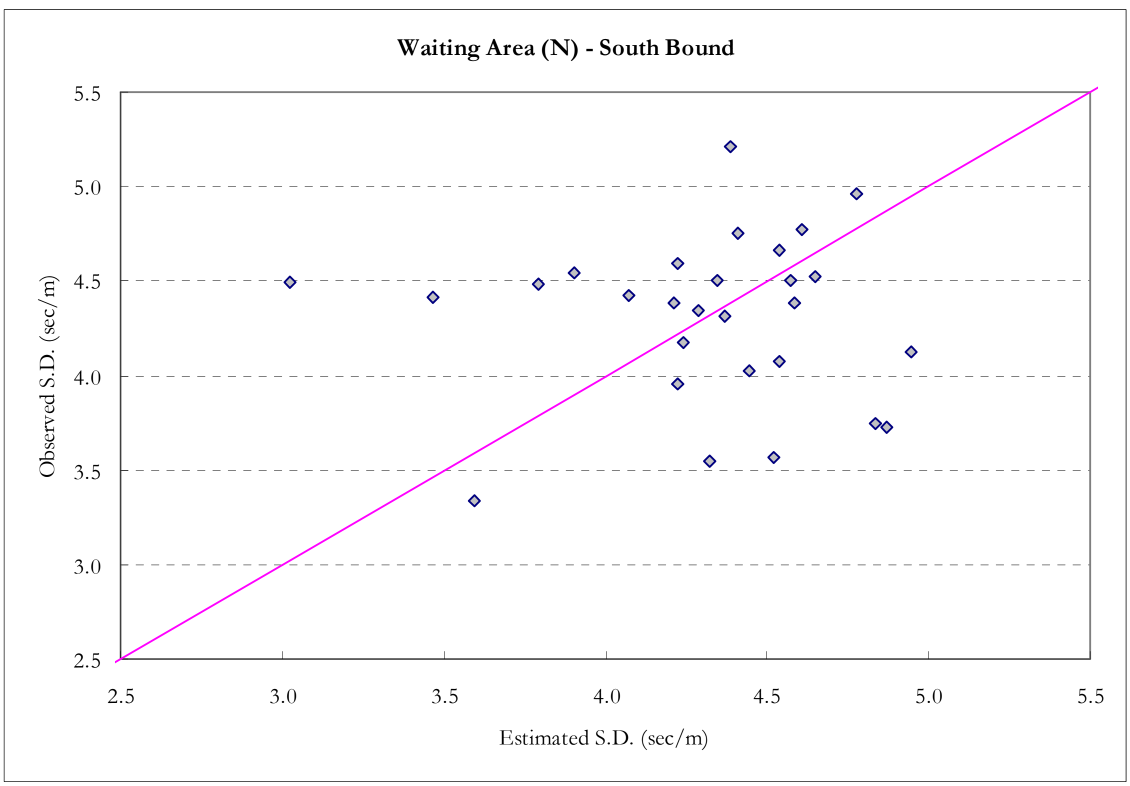

Figure 7. Observed vs Estimated Standard Deviation of Mean Walking Times

8. CONCLUSIONS

One of the most busiest and congested signalized crosswalks at Causeway Bay in Hong Kong was selected for calibration of the Pedestrian Simulation (PS) model. The calibrated PS model can simulate the pedestrian movements within the study area particularly under conditions with heavy opposing flows. Based on the model inputs of pedestrian arrival and departure flow patterns, crosswalk layout, cycle times and pedestrian walking time function, which were calibrated using the data collected from the on-site video recording survey, the pedestrian flows and the walking times at the study signalized crosswalk were simulated. Comparison was made between the observed data and the simulated results. It is found that the comparison results were satisfactory.

The results clearly show that the PS model can provide estimation not only on average walking speed but also on their standard deviations. It is believed that the calibrated PS model for signalized crosswalk can serve as a practical tool for evaluating the pedestrian walking environment under different bi-directional flow conditions. Thus, the simulation results gained in this study should be useful for enhancing the current assessment/design standards in Hong Kong. It is also hoped that the developed model could be used as a reference source for other Asian cities with similar pedestrian flow characteristics. Further study is required to calibrate a generalized walking time function for signalized crosswalks which taking account the bi-directional flow effects ranging from uni-directional to heavy opposing flows. Model validation is also necessary.

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