Modeling Pedestrian Walking Speed at Signalized Crosswalks Considering Crosswalk Length and Signal Timing

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Abstract: Quantifying the effects of crosswalk length and signal timing on pedestrian walking speed is an important requirement for providing a rational safety assessment and improving existing operational policies at signalized intersections. This study investigates the effects of pedestrian green time (PG), crosswalk length and pedestrian crossing direction on pedestrian walking speed at signalized crosswalk. It is assumed that the pedestrian walking speeds consist of two components v_1 and v_2 at two consecutive halves of crosswalk. Empirical analysis shows that pedestrian walking speed increases as PG proceeds. Longer crosswalk corresponds to higher walking speed. Furthermore, a comparison of pedestrian speed models at PG and PFG (pedestrian flashing green time) demonstrates that pedestrian walking speeds at PFG are higher and more variable than at PG.

Keywords: Pedestrian Walking Speed, Crosswalk, Signal Timing, Crossing Direction

1. INTRODUCTION

Crosswalks are designated portions on a roadway to assist pedestrians desiring to cross it. They play a significant role in the safety and mobility performance of signalized intersections.

Pedestrian-vehicle conflict is considered as one of the most common safety problems at signalized intersections. Approximately one-third of the total traffic accident fatalities are pedestrians at signalized and unsignalized crosswalks in Japan (National Police Agency of Japan, 2013). Understanding pedestrian behavior at signalized crosswalk and identifying the influencing factors upon their behavior are essential to pedestrian safety assessment. Additionally, it helps improve the efficiency of operational policies at signalized intersection.

With regard to pedestrian behavior at crosswalk, walking speed is one of the important factors that may result in safety problems. However, most of the existing manuals and guidelines (e.g., Japan Society of Traffic Engineers, 2006) assume a constant pedestrian walking speed for the design and operation of signalized intersections without considering the effects of crosswalk geometry and signal timing.

Thus, this study aims to analyze the effects of crosswalk length, signal timing and crossing direction upon pedestrian walking speed at signalized crosswalks. The structure of this paper is as follows; after a literature review on pedestrian walking speeds, the analytical methodology of walking speed, data collection and processing are explained. The effects of various influencing factors on pedestrian walking speed are analyzed based on empirical data. Then, models are developed to represent pedestrian walking speeds at two halves of crosswalks. Next, the pedestrian walking speeds during pedestrian green time (PG) and pedestrian flashing green time (PFG) are compared. Last, the paper ends up with a summary of the analysis results and future works.

2. LITERATURE REVIEW

The walking speed and/or walking time of pedestrians are of prime importance in studying the operation and design of pedestrian facilities. Macroscopic approaches have been widely employed to analyze pedestrian speed such as in Navin and Wheeler (1969), Fruin (1971), Highway Capacity Manual (2010). However, compared to walkway and sidewalk, few studies addressed the issue of pedestrian walking speed at signalized crosswalks under the effects of intersection geometry and operation.

Tarawneh (2001) analyzed pedestrian walking speeds at various pedestrian facilities in Jordan. He found that pedestrian walking speeds at walkways, sidewalks and crosswalks are significantly different. Age, gender, group size and street width are considered as important factors in defining average pedestrian walking speeds.

Montufar et al. (2007) analyzed the difference of pedestrian walking speeds at sidewalks and signalized crosswalks. The effects of seasonality, age and gender of pedestrians were discussed. It concluded that pedestrian walking speeds at crosswalks are significantly different from those on sidewalks at a 95% confidence level. In general, pedestrians walk faster at crosswalk compared to on sidewalk and walkway.

Lam and Cheung (2000) studied pedestrian walking speeds at different walking facilities. They found that pedestrian free-flow speeds at outdoor walkways were lower than that at signalized crosswalks by 17%. It shows that the surrounding conditions of signalized crosswalks, e.g., the existence of turning vehicles, make pedestrians walk faster to clear the crosswalk.

Goh et al. (2012) analyzed pedestrian walking speed at signalized crosswalks and unsignalized crosswalks in Malaysia. They found that pedestrians at unsignalized crosswalk had significantly higher crossing speed than at signalized crosswalk. Age and gender are significant influencing factors of pedestrian crossing speed.

Asano et al. (2013) analyzed the pedestrian walking speeds during PFG. It was found that the crosswalk length and the distance to crosswalk from the instant pedestrian positions at the onset of PFG had positive impacts to pedestrian walking speeds. Because pedestrians had limited time to cross during PFG, they increase their speeds especially when provided longer crosswalk or shorter entering time. In addition, higher pedestrian demands result in lower pedestrian walking speeds.

However, few efforts have been made to analyze the effects of crosswalk length, signal timing and pedestrian crossing direction on pedestrian walking speeds at crosswalks. For instance, PFG as part of pedestrian green phase typically relates to higher walking speed. Other influencing factors, e.g., crosswalk geometric characteristics, pedestrian crossing direction, are also assumed to have effects. Therefore, this study models pedestrian walking speed as a function of these factors and provides insights into pedestrian behavior analysis for safety assessment.

3. METHODOLOGY

3.1 Definitions of speed analysis

During PG and PFG, pedestrian crossing behavior is affected by various factors such as crosswalk geometry, signal phase, presence of turning vehicles or other crossing pedestrians. For simplification, the following assumptions are made to develop a model which can stochastically represent pedestrian maneuver at signalized intersections during PG interval. Pedestrian walking speeds during PFG were analyzed in the same way (Asano et al., 2013) by applying the same definitions as this paper. Note that Japan has a left-hand traffic system. All of the following analysis and discussions are for the left-hand traffic.

In the case of the conflicts between pedestrians and turning vehicles, pedestrian crossing direction at the crosswalk is an important factor. Here pedestrian crossing direction is defined as pedestrian movement direction based on two categories: near-side and far-side of crosswalk. Near-side means the side where pedestrians and exiting turning vehicles have conflict and far-side is the opposite side as shown in Figure 1.

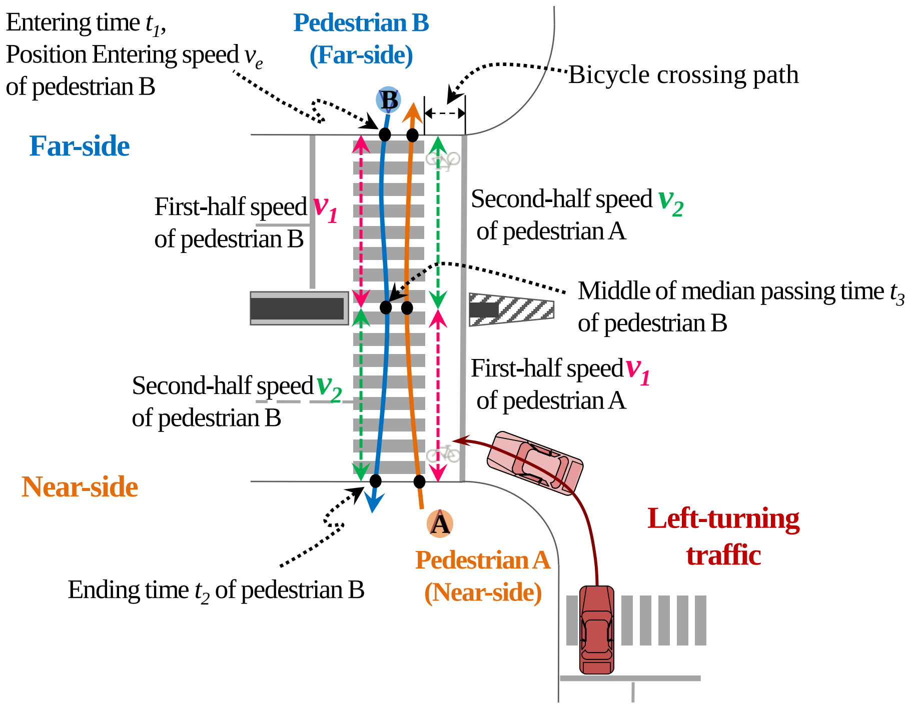


Figure 1. Illustration of pedestrian walking speeds

The walking speeds are assumed to consist of two consecutive travel speeds v_1 and v_2 as shown in Figure 1. They are defined as follows:

- First-half speed v_1: Travel speed in the first half of the crosswalk (m/sec).
- Second-half speed v_2: Travel speed in the second half of the crosswalk (m/sec).

As for the comparison of v_1 and v_2, note that the first half of the crosswalk for near-side pedestrians corresponds to the second half of the crosswalk for far-side pedestrians, and vice versa. Pedestrians are assumed not to react to others or to take evasive actions to avoid any conflict along their paths.

In order to analyze the behavior when pedestrians approach the crosswalk, the following variables are defined.

- Elapsed time percentage of PG: Pedestrian walking speed is assumed to be affected by the entering timing. For instance, if a pedestrian enters the crosswalk immediately after the onset of PG, he/she has enough time to pass crosswalk. However, if the pedestrian enters the crosswalk at the end of PG, there is a high probability that signal changes to red before the pedestrian finishes crossing. Therefore, elapsed time percentage of PG is defined as the elapsed time after the onset of PG divided by PG duration. The reason of generalizing elapsed time is that various crosswalks have different PG lengths and the arrival of crossing pedestrians and conflicting turning vehicles may also change as green time proceeds.

- Entering speed: It is defined as the spot speed when pedestrian enters the crosswalk. Apparently, certain differences exist for those pedestrians who wait near the crosswalk during red phase and those arrive in the middle of PG.

3.2 Speed distribution models during pedestrian green time

First-half speed v_1 is estimated by dividing the walking distance from the entering position of the crosswalk to the passing position at middle cross-section by the elapsed time, as shown in Figure 1. Observed crossing speeds are modeled using the cumulative Gamma distribution.

$$\begin{aligned} &\Pr(v_1 = x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \exp\left(-\frac{x-\gamma}{\beta}\right)(x-\gamma)^{\alpha-1} \\ &\alpha = f(y_{1,1}, y_{1,2}, ..., y_{1,n}) = \alpha_{1,1}y_{1,1} + \alpha_{1,2}y_{1,2} + ... + \alpha_{1,n}y_{1,n} + \alpha_{1,n+1} \\ &\beta = f(y_{2,1}, y_{2,2}, ..., y_{2,n}) = \alpha_{2,1}y_{2,1} + \alpha_{2,2}y_{2,2} + ... + \alpha_{2,n}y_{2,n} + \alpha_{2,n+1} \\ &\gamma = f(y_{3,1}, y_{3,2}, ..., y_{3,n}) = \alpha_{3,1}y_{3,1} + \alpha_{3,2}y_{3,2} + ... + \alpha_{3,n}y_{3,n} + \alpha_{3,n+1} \end{aligned} \quad (1)$$

Where,

α : shape parameter,
β : scale parameter,
γ : location parameter,
$y_{i,1}, \ldots y_{i,n}$: independent variables,
$\alpha_{1,1}, \ldots, \alpha_{1,n}, \alpha_{2,1}, \ldots, \alpha_{2,n}$, and $\alpha_{3,1}, \ldots, \alpha_{3,n}$: model coefficients estimated by the maximum likelihood method, and
$\Gamma(\alpha)$: Gamma function, which is given by the following equation.

$$\Gamma(\alpha) = \int_0^{\infty} t^{\alpha-1} \exp(-t)dt \quad (2)$$

Gamma distribution enables to represent various types of skewed distributions. The characteristics of its parameters are explained as follows. The scale parameter represents the skewness of the distribution. The larger the parameter is, the smaller the skewness becomes. In addition, larger scale parameters correspond to larger average values of the distributions. The shape parameter determines the variation of the distribution. Smaller shape parameter corresponds to more concentrated distribution. The location parameter explains the domain of definition. The probability is equal to zero if $x<\gamma$. Since pedestrian speeds take non-negative values, the location parameter should also be non-negative value.

Second-half speed v_2 is modeled in a similar way. Taken together, based on observed data the walking distance at the first half of the crosswalk is used to estimate v_1 whereas the walking distance in the second half of the crosswalk is used to estimate v_2.

4. DATA COLLECTION

4.1 Study sites

Seven crosswalks at five signalized intersections which are located in Nagoya City, Japan, are selected as study sites. Table 1 shows the crosswalk geometry and signal settings at each site. Every study site is four-leg intersection. Pedestrian and vehicle volumes are the average hourly volumes during the observation period. The detailed phase sequences and lengths are shown as Tables 2 and 3. Kanayama, Ueda, Otsu and Fushimi are operated by four-phase signal control with protected phases for right-turn traffic. Although Yamada intersection is operated by a lagging right-turn sequence, the objective crosswalk at Yamada intersection has protected phases for right-turn traffic as in the other 4 intersections. Thus the East crosswalk of Yamada was also analyzed. S, N, E and W in Tables 2 and 3 represent South, North, East and West approaches, respectively.

The crosswalk lengths range from 16m to 36m. The cycle lengths at most sites are 160s, except at Yamada with a cycle length of 170s. In this study, bicycle crossing path (approximately 2m width as illustrated in Figure 1) is regarded as part of crosswalk width because pedestrians are frequently observed to use this path for crossing.

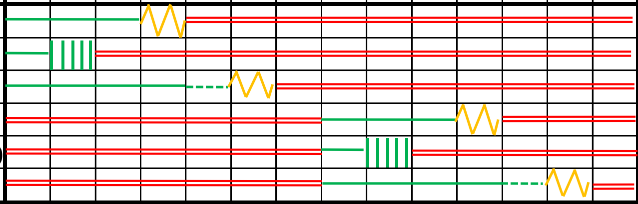
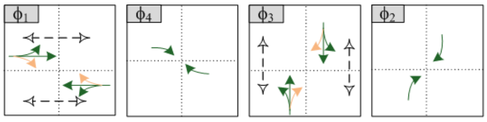
Table 4 shows the observation periods and the number of data samples. These intersections are located in urban areas and most of road users are ordinary adults. The elderly and pupils were rarely observed.

The positions of pedestrians at every 0.5s are manually extracted from observation videos by using the image processing system *TrafficAnalyzer* (Suzuki and Nakamura, 2006). Then, the coordinates in these images are converted to global coordinates through projective transformation. Kalman smoothing method is applied to estimate trajectories and speeds of pedestrians at each time interval.

Table 1. Geometric characteristics and traffic conditions at observed sites

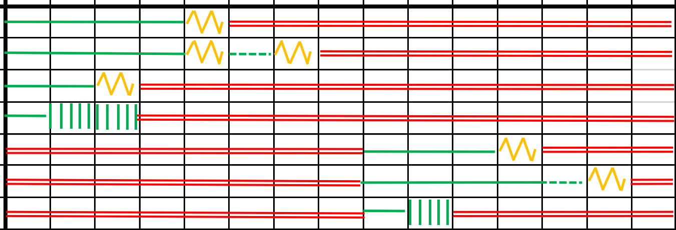
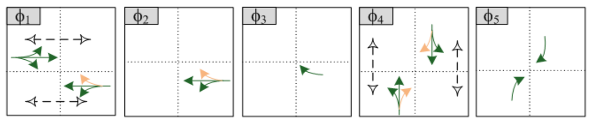
Intersection name	Objective approach	Crosswalk geometry (m)		Phase length (sec.)		Cycle length (sec.)	Pedestrian volume (ped/h)	Left-turning volume (veh/h)
		Length	Width	PG	PFG			
Kanayama	East	16.2	5.8	54	6	160	180	148
	North	36.2	5.8	39	9		335	124
Ueda	East	28.7	5.7	45	10	160	34	46
	South	20.8	5.2	54	8		90	176
Otsu	West	34.1	6.3	37	10	160	288	94
Fushimi	South	35.4	6	40	10	160	326	122
Yamada	East	15.2	5.7	80	6	170	43	50

Table 2. Signal phase sequences and timings for the four-phase signal control

Mode		Signal phasing length (sec.)														Cycle length (sec.)
		φ1				φ2			φ3				φ4			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
E-W	Vehicle															
	Pedestrian (location S and N)															
	Right-turning vehicle															
S-N	Vehicle															
	Pedestrian (location E and W)															
	Right-turning vehicle															
Intersection name	Kanayama	39	9	3	3	7	2	5	54	6	5	3	17	2	5	160
	Ueda	54	8	2	3	9	2	5	45	10	4	4	7	2	5	160
	Otsu	48	10	1	4	17	2	5	37	10	2	4	12	2	6	160
	Fushimi	40	10	2	4	7	2	5	62	7	3	4	8	1	5	160
Signal phase plan																

Green ----- Right-turning arrow |||| Pedestrian flashing green Amber Red

Table 3. Signal phase sequences and timings for Yamada intersection

Mode		Signal phasing length (sec.)															Cycle length (sec.)
		φ1			φ2		φ3			φ4				φ5			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
E to W	Through and left-turning vehicle																
	Right-turning vehicle																
W to E	Vehicle																
E-W	Pedestrian (location S and N)																
S-N	Through and left-turning vehicle																
	Right-turning vehicle																
	Pedestrian (location E and W)																
Intersection name	Yamada	31	8	3	1	3	12	3	5	80	6	2	4	5	2	5	170
Signal phase plan																	

Green ----- Right-turning arrow |||| Pedestrian flashing green Amber Red

Table 4. Observation periods and the number of subject pedestrians

Intersection name	Objective approach	Observation period	Number of subject pedestrians		
			Near-side	Far-side	Total
Kanayama	East	9:00-13:00 10/19/2012	345	250	595
	North	9:30-13:00 10/19/2012	650	578	1228
Ueda	East	7:00-10:00, 14:00-16:30 11/29-30/2012	166	136	302
	South	7:00-10:00, 14:00-16:30 11/29-30/2012	179	188	367
Otsu	West	10:00-11:00, 14:00-15:00 10/31/2012	188	257	445
Fushimi	South	10:00-11:00, 14:00-15:00 11/5/2012	271	319	590
Yamada	South	7:00-9:30, 14:30-17:00 11/8-9/2012	278	155	433

5. ANALYSIS ON PEDESTRIAN WALKING SPEEDS

Figure 2 shows the cumulative distribution and frequency of first-half and second-half speeds for near-side approaching pedestrians at the east crosswalk of Ueda intersection. Few pedestrians are found to have high speeds over 2.8m/sec and the first-half and second-half have narrow distributions. One possible reason is that pedestrians have the priority of way at the crosswalk and also have enough time to cross during PG. In addition, first-half speeds are significantly higher than second-half speeds at a 95% confidence interval according to the paired t-test as shown in Figure 2. It can be attributed to the fact that pedestrians usually slow down at the end of crossing maneuver.

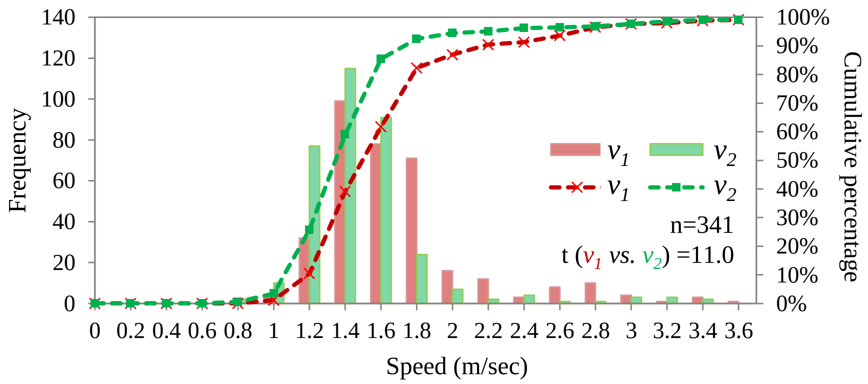
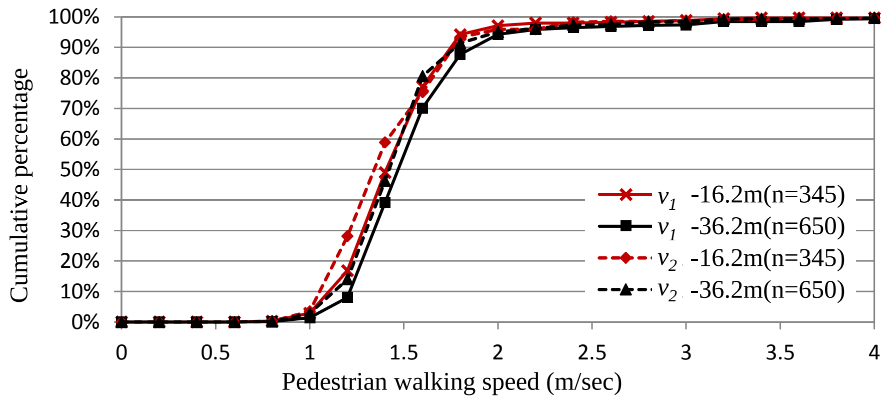


Figure 2.First-half speed and second-half speed distributions
(Near-side of East crosswalk, Ueda intersection)

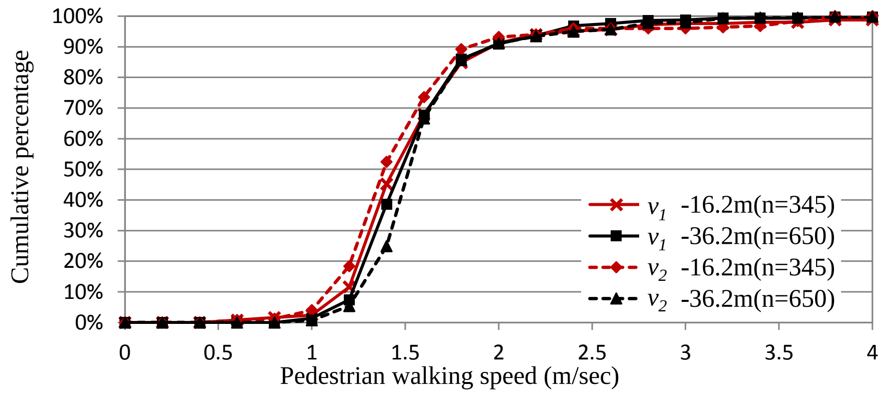
Moreover, pedestrian walking speeds were analyzed against crosswalk length, elapsed time percentage of PG and crossing directions.

For the effect of crosswalk length, Figure 3 shows the walking speeds at two crosswalks with different lengths. They are North crosswalk (36.2m) and East crosswalk (16.2m) of Kanayama intersection. The speed distributions at the longer crosswalks shift to right side. It indicates that though pedestrians have sufficient time to pass the crosswalk during PG, they may be aware of the conflicts with turning vehicles. Provided with longer crosswalks and more potential conflicts, pedestrians tend to walk faster to pass the crosswalk.

The effect of elapsed time percentage of PG was analyzed for first-half and second-half speeds for near-side approaching pedestrians at the north crosswalk of Kanayama intersection. The results are shown in Figure 4. Both of the first-half and second-half speeds increase as PG proceeds. In reality, pedestrians who enter the crosswalk in the middle of PG, cannot predict the termination of green phase. Therefore, they tend to have higher speeds at the crosswalk. It is clear in Figure 4 that at the end of PG, when elapsed time percentage of PG is 80%~100%, pedestrian speeds are significantly higher than before.

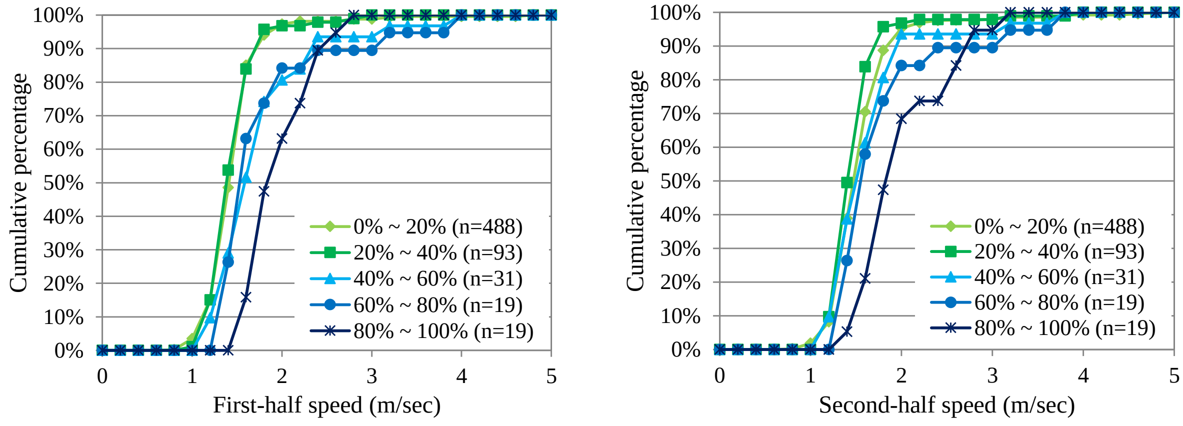


(a) Pedestrian walking speed (Near-side)



(b) Pedestrian walking speed (Far-side)

Figure 3. Cumulative speed distributions by crosswalk length



(a) First-half speed (b) Second-half speed

Figure 4. Cumulative speed distributions by elapsed time percentage of PG
(Near-side of North crosswalk, Kanayama intersection)

In addition, the effect of crossing directions (i.e., near-side and far-side) was examined. Figure 5 shows the average first-half and second-half speeds for each of near-side and far-side incoming pedestrians. For near-side pedestrians, first-half speeds are higher than second-half ones; whereas for far-side pedestrians, second-half speeds are higher than first-half ones. A direct reason is that both of the near-side and far-side incoming pedestrians have potential conflicts with turning vehicles at the near-side crosswalk. Thus they tend to hurry up to pass the conflict area.

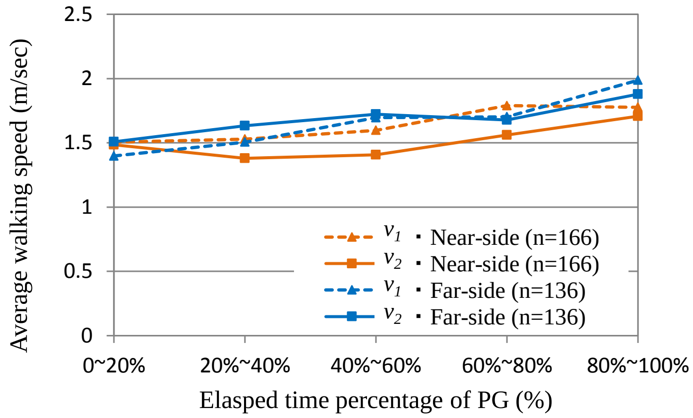


Figure 5. Average first-half speed and second-half speed by elapsed time percentage of PG

6. MODEL ESTIMATION

6.1 Model estimation results

Analysis results show that first-half and second-half speed distributions are left-right asymmetric, as presented in Figure 2. In this regard, several distributions such as log-normal distribution and Gamma distribution can represent the left-right asymmetric ones. In this study, Gamma distribution is employed to model first-half and second-half speed distributions.

Table 5 shows the estimated parameters for first-half and second-half speed distributions. Note that entering speed is a significant parameter in the first-half speed model and first-half speed is a significant parameter in the second-half speed model. It indicates that the speeds at upstream section are closely related to the speed profiles at the downstream section. Crosswalk length has positive impact to the shape parameter, suggesting that pedestrians have higher speeds along the longer crosswalk. The positive coefficient of near/far side dummy shows that far-side pedestrians have higher speeds than near-side pedestrians, which is consistent with the results of empirical analysis. Note that elapsed time percentage of PG is significant to the scale parameter only in first-half speed model, implying that pedestrians are more conscious of the remaining time to green end at the first half crosswalk thus have higher speeds when crossing the first half of the crosswalk. Elapsed time percentage of PG implies the timing when pedestrians start crossing. PG lengths at objective crosswalks are longer than 35s and pedestrians cannot recognize how much time is exactly left. In addition, not all of the pedestrians will accelerate when the elapsed time from the onset of PG is long. Therefore, the elapsed time from the onset of PG will affect the variation of pedestrian speed distribution, especially for first-half speed.

Note that although the other factors, such as peak and off-peak periods, pedestrian demand and the existence of conflicting turning vehicles, were also examined. These factors were found not significant, thus excluded from the models.

Table 5. First-half and second-half speed model

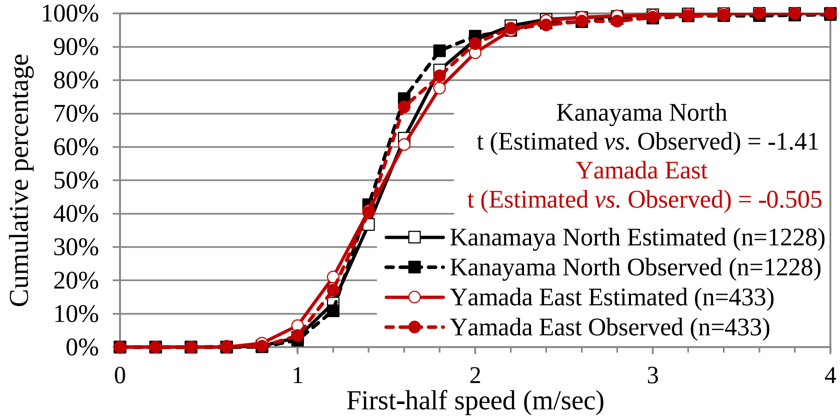
	Variables	First-half speed		Second-half speed	
		Coefficients	t-value	Coefficients	t-value
Shape parameter α	Entering speed (m/sec)	7.47	17.7		
	First-half speed (m/sec)			-2.10	-4.24
	Crosswalk length (m)	0.720	14.3	0.695	14.5
	Near-side:0, Far-side:1	4.19	7.62	4.10	6.80
	Constant	1.93	1.40	22.8	13.0
Scale parameter β	Entering speed (m/sec)	3.91×10^{-3}	9.65		
	First-half speed (m/sec)			0.0199	25.8
	Crosswalk length (m)	-1.06×10^{-3}	-13.7	-6.00×10^{-4}	-12.3
	Near-side:0, Far-side:1	-4.14×10^{-3}	-6.55	-1.59×10^{-3}	-3.20
	Elapsed time percentage of PG (%)	1.85×10^{-3}	3.98		
	Constant	0.0697	25.4	0.0256	12.4
Number of sample		3960		3960	
Log likelihood		-126		-150	
Initial log likelihood		-1430		-1511	
χ^2 value		2608		2722	
Adjusted R^2		0.912		0.901	

In order to present the characteristics of the models and the sensitivity of specific parameters, Monte-Carlo simulation is carried out in the next section for a better understanding of pedestrian walking speed.

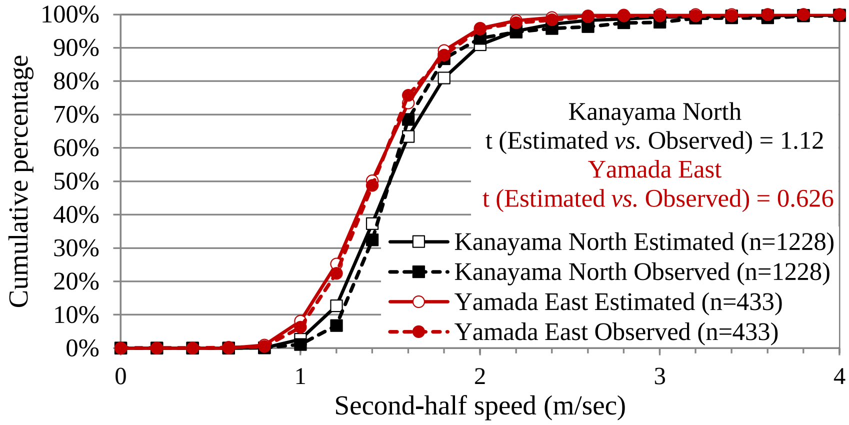
6.2 Monte-Carlo simulation for model validation

According to the developed model in Table 5, it is still difficult to analyze the relationship between specific variables and speed distributions under different combinations of shape and scale parameters. In order to validate the model characteristics, a Monte-Carlo simulation is applied to North crosswalk of Kanayama intersection and East crosswalk of Yamada intersection. The same number of estimation is set as observed data. All of the variables, e.g., elapsed time percentage of PG, entering speed, first-half speed, near/far side coming pedestrian demand are based on observed data.

Figure 6 shows the comparison of observed and estimated cumulative speed distributions at subject crosswalks. No significant difference is found between these 2 curves according to two sample t-test for difference for means (unequal variances) at a 95% confidence interval as shown in Figure 6, which demonstrates the models can well represent the speed distribution.



(a) First-half speed



(b) Second-half speed

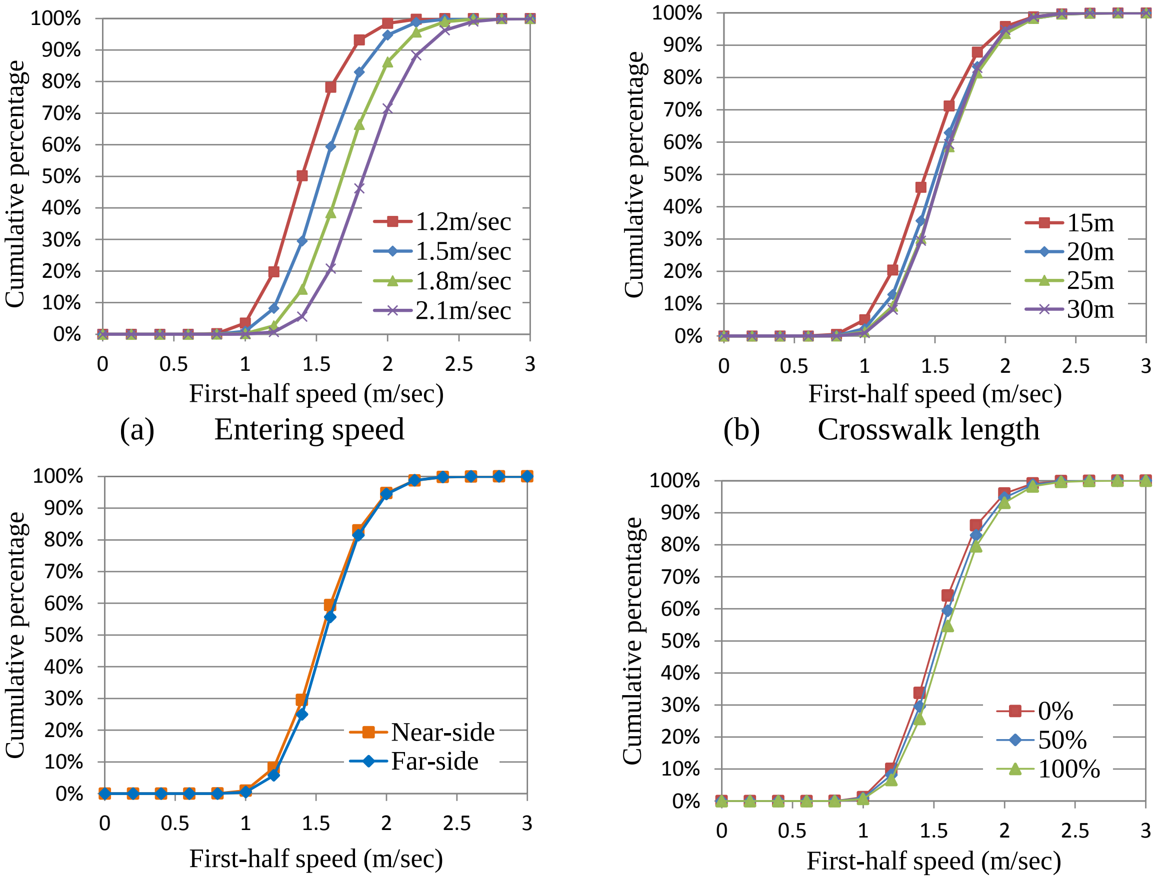
Figure 6. Validation of Monte-Carlo simulation results versus observed data

6.3 Sensitivity analysis of speed distribution models

Furthermore, sensitivity analysis is conducted in order to illustrate the impact of specific variables on speed distributions. According to field data characteristics, variables for the basic case are set as:

- Crosswalk length: 30m,
- Crossing direction: near-side,
- Entering speed: 1.5m/sec, and
- Elapsed time percentage of PG: 50%.

Figure 7 presents the sensitivity analysis results for first-half speed. Entering speeds are set to be 1.2, 1.5, 1.8 and 2.1 m/sec, respectively. The results in Figure 7 (a) show that first-half speeds get higher with increasing entering speed. When crosswalk length is changed from 15 to 30m as shown in Figure 7 (b), longer crosswalks are found to have higher first-half speed. Figure 7 (c) shows the speed distributions for both pedestrians coming from near-side and far-side. Pedestrians coming from Far-side tend to have higher speeds than near-side. Besides, when the values of elapsed time percentage of PG become larger, (i.e., 0%, 50% and 100%), first-half speeds accordingly get higher.

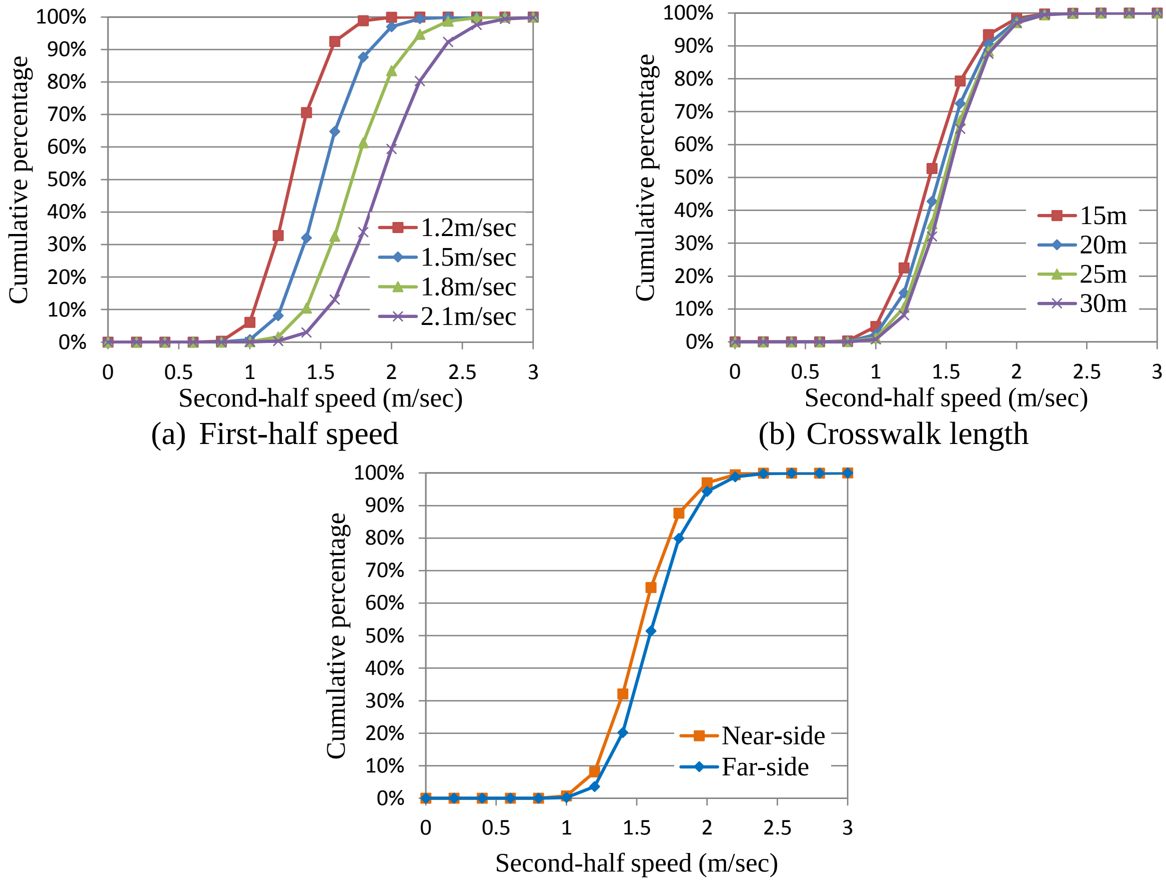


(a) Entering speed (b) Crosswalk length

(c) Crossing direction (d) Elapsed time percentage of PG

Figure 7. Sensitivity analysis of first half speed distribution model

Figure 8 presents the sensitivity analysis results of second-half speed. It shows in Figure 8 (a) that the distributions of second-half speeds shift to higher values when first-half speed changes from 1.0 to 2.1 m/sec. The similar tendency can be identified in Figure 8 (b) when crosswalk length changes from 15 to 30 m. It indicates higher speeds along longer crosswalks. The influence of crossing direction is shown in Figure 8 (c). Far-side coming pedestrians tend to have higher speeds than near-side. Moreover, it is noted that the variations of second-half speeds for near-side and far-side coming pedestrians are larger than those of first-half speeds. In reality, far-side coming pedestrians typically increase their speeds at the second half of crosswalk.



(a) First-half speed (b) Crosswalk length

(c) Crossing direction

Figure 8. Sensitivity analysis of second half speed distribution model

6.4 Comparison to speed models during PFG

In order to illustrate the impact of signal phase on pedestrian walking speeds, Monte-Carlo simulation is applied to North crosswalk of Kanayama intersection during PG and PFG. Basic settings of influencing factors are shown as follows.

Pedestrian walking speed model during PG:

- Crosswalk length: 36.2m,
- Crossing direction: near-side,
- Entering speed (during PG): 1.8m/sec,
- Approaching speed (during PFG): 1.8m/sec,
- Elapsed time percentage of PG (during PG): randomly generated, and
- Entering time to crosswalk (during PFG): randomly generated.

In the simulations, 1000 pedestrians are generated during PG and PFG. Note that all of the pedestrians pass the crosswalk during PG, whereas pedestrians will choose to go or stop at the onset of PFG (Asano et al, 2013). Only pedestrians who chose to go are analyzed for their first-half and second-half speed. The cumulative distributions are shown in Figure 9. It demonstrates that pedestrian walking speeds during PFG are higher than PG. In addition, the variation of speeds during PFG is larger than PG. Furthermore, first-half speeds are higher than second-half speeds, especially during PFG. In reality, pedestrians enter the crosswalk with high speed, then decrease their speed when they will finish crossing. Pedestrians less change their speeds during PG provided with sufficient green time for crossing. However, when the signal changes to PFG, pedestrians rush into crosswalk at higher speeds. Less attention paid to conflicting turning vehicles may lead to risky situations for pedestrians.

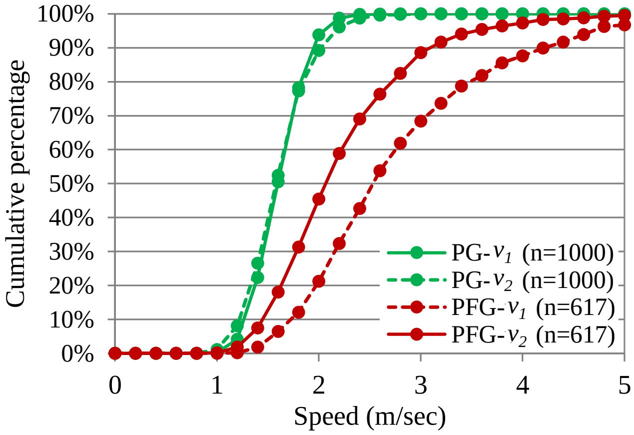


Figure 9. Comparison of speed models during PG and PFG

7. DISCUSSIONS AND CONCLUSIONS

In this paper, pedestrian walking speeds at the first-half and second-half crosswalk during PG were analyzed and modeled. It is concluded that pedestrian walking speed is significantly affected by crosswalk length, elapsed time percentage of PG and crossing direction.

Empirical analysis showed that the first-half and second-half speeds during PG increase as pedestrian green time proceeds. Furthermore, downstream walking speeds are significantly affected by upstream walking speeds. Longer crosswalk corresponds to higher walking speed. In order to quantify the effects of various influencing factors on the randomness of pedestrian behavior at crosswalks, Gamma distribution was employed to model both of the first-half and second-half speed distributions. It is found that in the first-half speed model, entering speed and crosswalk length are the most significant influencing factors, whereas elapsed time percentage of PG affects the speed variation. As for second-half speed, crossing direction was identified as a more significant factor than in the first half speed model. It implies that far-side pedestrians tend to speed up and avoid potential conflicts with turning vehicles when they reach the second half of crosswalks.

Through comparing pedestrian walking speeds during PG and PFG, it was demonstrated that pedestrian walking speeds during PFG are higher than during PG. In addition, the variations of speed distributions during PFG are larger than PG. In reality, pedestrians change less their speeds during PG provided with sufficient green time for crossing. However, when the signal changes to PFG, pedestrians rush into crosswalk at higher speeds. Less attention paid to conflicting turning vehicles may lead to risky situations for pedestrians.

As for future work, other influencing factors such as age, gender and trip purposes are also supposed to be incorporated in the pedestrian walking speed modeling, which may provide a more sophisticated presentation of pedestrian behavior under various traffic and operational conditions.

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