The impacts of signal timing and crosswalk length upon pedestrian speeds at signalized crosswalks

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Quantifying the effects of signal timing and crosswalk geometry on pedestrian speed is an important requirement for improving existing operational policies and for providing a rational safety assessment at signalized intersections. The objective of this paper is to analyze the effects of signal timing, crosswalk length and pedestrian origin-destination on pedestrian travel speed at signalized crosswalks. It is assumed that the speed profiles of crossing pedestrians are consisted of two consecutive travel speeds v_1 and v_2. Collected empirical data revealed that pedestrian travel speed increases as pedestrian green interval proceeds. Moreover, pedestrians show higher travel speeds at long crosswalks..

Key Words : *Pedestrian travel speed, Signal timing, Crosswalk length, Pedestrian demand, Origin-Destination*

1. INTRODUCTION

Crosswalks are designated portions on a road, employed to assist pedestrians desiring to cross the street and play a significant role in the safety and mobility performance of signalized intersections.

Although signalized crosswalks are operated in a way to give pedestrians prioritized right of way, more than one-third of the total traffic accident fatalities are pedestrians[1)]. The threat to pedestrian safety mainly comes from the interaction with turning traffic in which users' behavior including pedestrians and drivers is one of the main contributing factors. Understanding pedestrians' behavior at signalized crosswalks and identifying the influencing factors upon their maneuver is essential to assess the safety performance. Simultaneously, it is of prime importance to rationally improve the efficiency of exiting operational policies as well.

Pedestrian crossing speed is one of the most important parameters in analyzing pedestrian behavior and its randomness. However, most of the existing manuals and guidelines for the design and operation of signalized intersections assume a constant pedestrian crossing speed without considering the effects of crosswalk geometry, signal timing and pedestrian demand.

Thus, this study aims at macroscopically analyzing the effects of pedestrian signal timing, pedestrian origin- destination, pedestrian demand and crosswalk geometry (length and width) upon pedestrian travel speed at signalized intersections. The structure of this paper is as follows: after introduction and the literature review, the methodology of analyzing pedestrian speed is explained. This is followed by data collection and processing. Then a comprehensive discussion on the effects of various influencing factors on pedestrian speed is presented. Furthermore, empirical models which represent pedestrian travel speeds at signalized crosswalks are developed. Finally, the paper ends up with summary of the results and future works.

2. LITERTURE REVIEW

The walking speed and/or walking time of pedestrians are of prime importance in studying the operation and design of pedestrian facilities. Generally, macroscopic pedestrian speed analysis was first started by Navin and Wheeler[2] and Fruin[3] followed by many researchers and have been adopted by Highway Capacity Manual[4]. Most of the existing works in this respect attempted to investigate the variations in walking speed at other pedestrian facilities such as walkways and sidewalks. Few studies addressed the issue of pedestrian walking speed at signalized crosswalks without considering the effects of intersection geometry and operation.

Tarawneh[5] analyzed pedestrian speed at various pedestrian facilities in Jordan. He found that pedestrian walking speeds at walkways, sidewalks and crosswalks are significantly different and age, gender, group size and street width are very important factors in defining average pedestrian walking speed. However, the effects of signal control parameters, pedestrian origin-destination and crosswalk geometry on pedestrian speeds at signalized crosswalks were not considered.

Montufar, et al.[6] analyzed the difference in pedestrian speed between sidewalks and signalized crosswalks. They also analyzed the effect of seasonality in the walking speed of pedestrians, taking into account age and gender. It is concluded that pedestrian walking speeds at crosswalks are significantly different from that at sidewalks at 95% confidence level. In general, pedestrians walk faster when they cross a crosswalk compared to walking along a sidewalk or walkway. However, they did not analyze the effects of signal timing and crosswalk geometry on pedestrian speeds at crosswalks.

Lam and Cheung[7] studied pedestrian walking speed at different walking facilities. They found that pedestrian free-flow speed at outdoor walkways is lower than that of signalized crosswalks by 17%. They suggested that the surrounding conditions of signalized crosswalks such as the existence of turning vehicles make pedestrians walk faster in order to clear the crosswalk. However they did not go deeply to analyze the effects of pedestrian signal timing, crosswalk geometry and pedestrian demand on the pedestrian travel speed.

3. METHODOLOGY

In this paper, pedestrian origin-destination is defined as pedestrian movement direction which is divided into two categories; near-side or far-side. Near-side pedestrians are those who start crossing from the side of the vehicular traffic that is exiting the intersection while far-side pedestrians are those who start crossing from the side of the incoming vehicular traffic as shown in **Fig.1**.

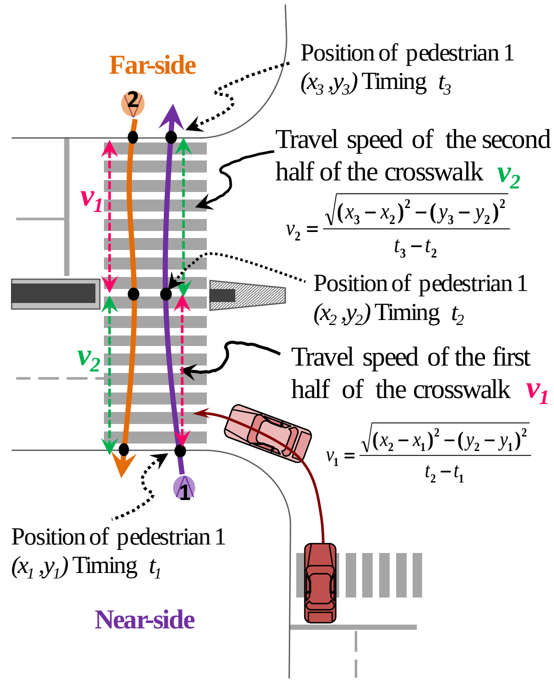
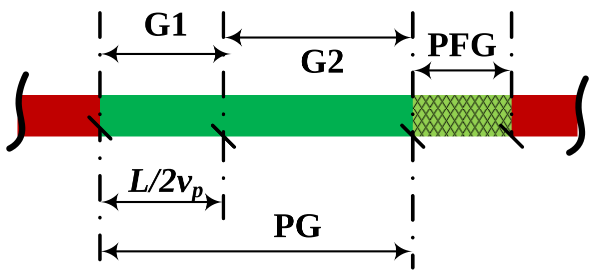


Fig.1 Definition of pedestrian travel speeds.



Where: L is crosswalk length (m), v_p is average pedestrian speed (assumed 1m/sec), PG is pedestrian green (sec), PFG is pedestrian flash green (sec).

Fig.2 Dividing pedestrian green time into 3 intervals.

For the purpose of this study, it is assumed that the speed profiles of crossing pedestrians are consisted of two consecutive travel speeds v_1 and v_2. **Fig.1** illustrates the estimated travel speeds which are defined as follows:

-First half travel speed (v_1): The travel speed in the first half of the crosswalk (m/sec).

-Second half travel speed (v_2): The travel speed in the second half of the crosswalk (m/sec).

When comparing v_1 and v_2, it is important to note that the first half of the crosswalk for near-side pedestrians is the second half for far-side pedestrians. **Fig.2** shows how to estimate travel speeds (v_1 and v_2). Pedestrian origin-destination is defined as pedestrian movement direction which is divided into two categories; near-side or far-side. Furthermore, pedestrians who faced and did not face left-turning vehicles are also distinguished.

4. DATA COLLECTION AND PROCESSING

In order to analyze the pedestrian speed at crosswalks, video data was collected at three signalized crosswalks. **Table 1** presents the observation dates, the geometric and signal timing characteristics of the study sites. All these sites are located in Nagoya City, Japan.

The observed crosswalks have significantly different geometric and operational characteristics such as crosswalk length and signal timing parameters. All the observed intersections are operated by a 4-phase plan where a shared through left-turning phase is followed by an exclusive right turning phase.

The trajectories of pedestrians are extracted from video data by using the image processing system *TrafficAnalyzer* (Suzuki and Nakamura, 2006). The position of each pedestrian was extracted every 0.5 seconds. The point where the feet of the pedestrian are touching the ground is the reference observation point.

It is important to note that all observed sites have high through traffic demand. **Table 2** presents the percentage of pedestrian who face left-turning vehicles. In most of intersections, the number of pedestrians who face left turning vehicle is very high, especially in Nishi-Osu.

5. ANALYSIS ON PEDESTRIAN SPEEDS

Fig.3 and **Fig.4** show the mean, 15 percentile and 85 percentile of first half v_1 and second half v_2 travel speeds for near-side and far-side pedestrians respectively. It is obvious that the travel speeds for near-side and far-side pedestrians increase as the green interval proceeds. Therefore, the travel speed distributions in G2 are significantly higher from those in G1 at all intersections at 95% confidence interval. In G1, due to the interaction between pedestrians, their travel speeds are lower compared to those in G2. Furthermore, pedestrians approaching the crosswalk during G2 cannot predict when the green indication will terminate, thus they tend to hurry up.

The travel speeds during pedestrian flash green interval PFG are presented for Imaike Intersection only

Table 1 Surveyed site characteristics

Intersection name		Imaike	Suemori-Dori2	Nishi-Osu
Crosswalk position		East Leg	South Leg	North Leg
Dimensions w(m)×L(m)		9m×20m	7m×18m	5m×36m
Survey hours		13:00-15:00	09:00-12:30	09:00-12:30
Cycle Length		140	140	160
Pedestrian green time(sec)	PG	35	47	38
	G1	10	9	18
	G2	25	38	20
Pedestrian flashing green time(sec)		8	8	10

Table 2 Observed number of pedestrians

Crosswalk		Imaike		Suemori-Dori2		Nishi-Osu	
Direction		Near-side	Far-side	Near-side	Far-side	Near-side	Far-side
Observed No. of pedestrians	G1	176	165	50	36	152	119
	G2	50	49	35	23	24	13
	PFG	20	11	4	3	2	5
	Total	246	225	89	62	178	137
Percentage of pedestrians who faced turning traffic		25%	83%	55%	94%	94%	99%

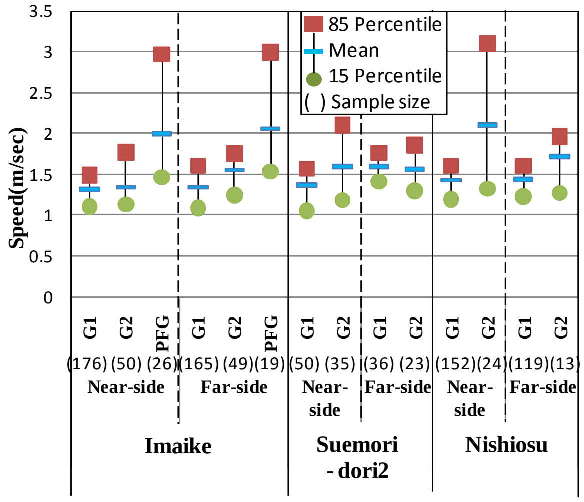


Fig.3 The mean and 15 percentile and 85 percentile of second half travel speeds v_1 in different signal intervals.

since the observed number of pedestrian during PFG at other sites is very small. **Fig.3** and **Fig.4** show that average pedestrian travel speed during PFG is significantly higher than those of G1 and G2. This can be explained that pedestrians expect the red signal to be indicated shortly, thus they try to clear the

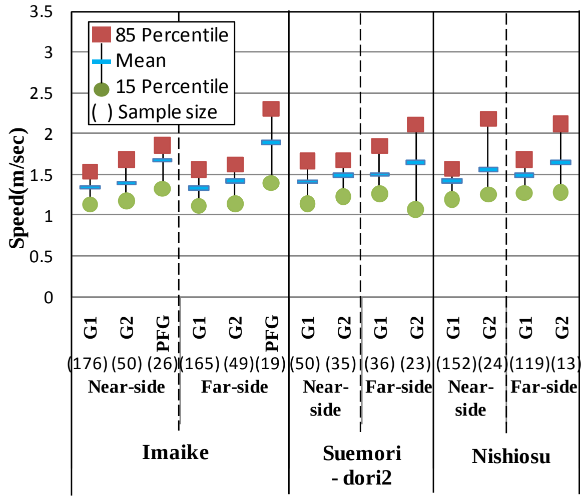


Fig.4 The mean and 15 percentile and 85 percentile of second half travel speeds v_2 in different signal intervals.

crosswalk as fast as possible.

Generally, it is concluded that the travel speeds v_1 and v_2 for the near-side and far-side pedestrians during G1 are not significantly different at 95% confidence interval. Whereas in G2, the second half travel speeds v_2 for far-side pedestrians are significantly higher than those of near-side pedestrians.

Moreover, by comparing the travel speeds v_1 and v_2 at the three sites (**Fig.3** and **Fig.4**), it is clear that the travel speeds at Nishiosu Intersection are significantly higher (95% significance level) which can be referred to the extremely long crosswalk.

Regarding the effect of turning vehicles, the analysis revealed that the mean travel speed (v_1 and v_2) for pedestrians who faced and did not face turning vehicles are not significantly different at 95% confidence level. Basically, the effect of turning vehicles on pedestrian speed is totally dependent on the circumstances when they meet, such as vehicle speed, vehicle type, etc. Therefore, it is difficult to reasonably assess the effects of turning vehicles in macroscopic analysis level.

6. PEDESTERIAN SPEED MODELING

In this section, models to represent the travel speed of pedestrians on crosswalks are introduced. To consider the stochastic behavior of pedestrians, it is assumed that their travel speed is normally distributed with linear mean and standard deviation relationships as a function of crosswalk geometry, pedestrian demand, and pedestrian origin-destination. Since the effects of various influencing factors, such as pedestrian demand and crosswalk length, on pedestrian travel speed are depending on pedestrian signal interval, different models are developed for G1, G2 and PFG.

Table 3 shows the developed first-half travel

Table 3 First half travel speed v_1 models in different pedestrian signal intervals.

Normal Distribution	Parameters	G1	G2	PFG
		v_1 $N(\mu,\sigma)$		
		Estimate (Sig.)		
μ	Const	1.3474 (0.000)	1.1138 (0.000)	2.0233 (0.000)
	Crosswalk length (*m*)	0.0045 (0.002)	0.0221 (0.003)	-
	Pedestrian demand* (*ped./hr/m_width*)	-0.0051 (0.000)		-
σ	Const	0.2419 (0.000)	-0.0644 (0.519)	0.7080 (0.000)
	Crosswalk length (*m*)	0.0043 (0.000)	0.0231 (0.000)	-
	Pedestrian demand* (*ped./hr/m_width*)	-0.0038 (0.000)	-	-
Log likelihood		-113.3367	-113.6195	-48.3157
Sample Size		698	194	45

Table 4 Second half travel speed v_2 models in different pedestrian signal intervals.

Normal Distribution	Parameters	G1	G2	PFG
		v_2 $N(\mu,\sigma)$		
		Estimate (Sig.)		
μ	Const	0.4283 (0.000)	0.5104 (0.000)	0.0027 (0.991)
	First half travel speed v_1 (*m/sec*)	0.7277 (0.000)	0.6143 (0.000)	0.3427 (0.000)
	Crosswalk length (*m*)	-	-	.04807 (0.000)
	Pedestrian demand*	-0.0023 (0.002)	-	-
	Dummy (Far-side=1, Near-	0.0210 (0.199)	0.0314 (0.462)	-
σ	Const	0.1492 (0.000)	-0.0302 (0.476)	0.0030 (0.970)
	First half travel speed v_1 (*m/sec*)	0.1139 (0.000)	0.1868 (0.000)	0.1584 (0.001)
	Crosswalk length (*m*)	-0.0044 (0.000)	-	-
	Dummy (Far-side=1, Near-	0.0494 (0.000)	0.0854 (0.005)	-
Log likelihood		104.0729	-37.1978	-48.3157
Sample Size		698	194	45

speed v_1 models for different pedestrian signal intervals, while **Table 4** shows the developed second half travel speed v_2 models. Travel speeds v_1 and v_2 during G1 are significantly affected by pedestrian demand per hour per meter width of the crosswalk which is not the case during G2 and PFG.

Furthermore, it is clear that crosswalk length is one of the most significant parameters and it has a positive relationship with pedestrian travel speed.

Table 3 shows that crosswalk length is a significant parameter in the v_1 models during G1 and G2 while it is not significant parameter in v_2 models. At long crosswalks approaching pedestrians speed up, so they can reduce the necessary time to clear the crosswalk, however after reaching half of the crosswalk, they tend to reduce their sped because they feel secure as they approach the other side of the crosswalk.

During PFG, it is difficult to clarify the significance of several parameters such as pedestrian origin-destination due to the few available samples. Thus it is necessary to collect more data to develop a reliable model.

7. CONCLUSIONS

In this paper, pedestrian travel speeds at signalized crosswalks were analyzed and modeled considering the effects of pedestrian signal timing, crosswalk length, pedestrian origin-destination and pedestrian demand.

It is concluded that pedestrian travel speed is significantly affected by pedestrian signal timing, crosswalk length, pedestrian origin-destination and pedestrian demand.

This research assumed that the speed profile of crossing pedestrians is composed from two consecutive travel speeds; the first speed v_1 is through the first-half of the crosswalk while the second one v_2 is through the second-half of the crosswalk. Empirical data showed that the travel speeds v_1 and v_2 during G2 are significantly different from those during G1. Furthermore, travel speeds during pedestrian flash green interval PFG are significantly higher than those during pedestrian green PG. Simultaneously, it is concluded that longer crosswalks have significantly higher travel speeds.

To quantify the effects of various influencing factors on the randomness of pedestrian behavior at crosswalks, normal distribution models for pedestrian travel speeds v_1 and v_2 were empirically developed. It is found that in the v_1 model during G1, pedestrian demand and crosswalk length are the most significant influencing factors, while during G2 crosswalk length is the most significant one. For defining v_2 during G1 and G2, crosswalk length becomes insignificant factor. This can be explained that pedestrian tend to speed up when they approach long crosswalks trying to reduce the necessary time to clear the crosswalk, however after reaching half of the crosswalk, they tend to slow down because they feel secure as they become closer to the end of the crosswalk.

The conducted analysis did not reveal any significant differences between the travel speeds of pedestrians who face and did not face turning vehicles. This indicates that analyzing the effect of turning traffic on pedestrian behavior need to be addressed microscopically.

Improving the developed travel speed models to consider the effects of age, gender and trip purpose is also necessary to provide a realistic presentation of pedestrian behavior under various traffic and operational conditions.

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