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Analyzing the Impact of Refuge Islands on Pedestrian and Driver Behavior at Unsignalized Mid-block Crosswalks

Xin Zhang[a]*, Hideki Nakamura[a], Yu Wu[a]

[a]*Graduate School of Environmental Studies, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan*

Abstract

In order to improve mobility and safety of pedestrians at unsignalized crosswalks, mid-block crosswalks with refuge islands are getting the attention of some traffic engineers in Japan. Refuge islands can make the crossing distance shorter and pedestrians only need to select the gaps of vehicles from one direction. However, their examples are very limited until today and their impacts on user behavior are still unclear. Thus, the objective of this paper is to understand pedestrian and driver behavior on two types of unsignalized mid-block crosswalks with and without the refuge island by analyzing driver's yield rate, pedestrian crossing speed, and vehicle speed. It was found that pedestrians tend to increase their speed when they encounter vehicles, and there is a significant reduction in their speeds on the refuge island. As a result of observations before and after implementing a refuge island, vehicle speed significantly decreased. It was also found that the yield behavior is influenced by crosswalk position and vehicles' approach speed.

Keywords: Mid-block crosswalk; Refuge island; Vehicle speed; Pedestrian speed; Yield behavior

1. Introduction

According to the annual report of the National Police Agency of Japan (1), approximately 30% of the total number of traffic accidents involve pedestrians walking on a crosswalk. Particularly, the percentage of elderly people whose age is more than 65 years old is increasing in recent years. The improvement of safety and mobility on the crosswalk is an urgent issue. In the field survey carried out by Japan Automobile Federation (JAF, 2016), 92.4% of vehicles did not yield to pedestrians at unsignalized crosswalks, even though the road traffic law in Japan defines that the priority should be given to pedestrians over vehicles. Installing a traffic signal light is a common way used for solving this

* Corresponding author. Tel.: +81-52-789-3832; fax: +81-52-789-3837.
E-mail address: zhang@genv.nagoya-u.ac.jp

issue by separating the moving paths of pedestrians and vehicles. However, some problems of signal settings are also observed, such as long delays and costs for implementation and maintenance. In European countries, refuge islands are one of the common solutions to improve safety and mobility of users at mid-block crosswalks. It is much easier for pedestrians to cross the road in two stages, since the refuge island can reduce the crossing distance and waiting time for pedestrians, separate conflicts in time and space, as well as provide an improved crossing environment (AASHTO, 2004). However in Japan the mid-block crosswalks with refuge islands has been rarely used, and the impact of refuge islands on user behaviors have not been thoroughly studied.

There are two types of mid-block crosswalks; mid-block crosswalks with and without a refuge island. For understanding the impact of the refuge island, it is recommended that the other geometric and traffic conditions should be the same. A before-after study is better to analyze the impact of refuge islands by comparing the traffic characteristics when vehicles pass through them, and when pedestrians cross them. Therefore, the objective of this study is to understand the impact of refuge islands on pedestrian and driver behavior at the unsignalized mid-block crosswalk. For analyzing pedestrian and driver behavior, this paper focuses on driver’s yield rate, pedestrian crossing speed and vehicle position and approaching speed on the mid-block crosswalk before and after implementation of a refuge island.

2. Literature review

Despite several examples of past studies on mid-block crosswalks, few studies focused on user behavior especially on mid-block crosswalks with a refuge island.

Sun et al. (2003) studied motorist-pedestrian interactions at uncontrolled mid-block crosswalks by modeling pedestrian gap acceptance and motorist yield behaviors. The relationship between pedestrian groups or individual pedestrians, gap acceptance of pedestrians and pedestrian waiting time were analyzed. However, they studied drivers’ yield behavior without considering vehicle speeds and positions when pedestrians entered the crosswalks. Bertulis et al. (2014) modeled driver yield rate by vehicles’ 85th percentile speed at unsignalized crosswalks and found that vehicles tend to stop or yield to pedestrians when their speeds are low enough. However, they only considered vehicles’ 85th percentile speed as an influencing factor of yield rate and this study was based on ordinary crosswalks without refuge islands. Therefore the effects of refuge islands on vehicle speed and yield rate are still unclear.

In Japan, one of the studies on the evaluation of unsignalized mid-block crosswalks was done by Ishiyama et al. (2018). The effect of mid-block crosswalk was analyzed by considering pedestrian crossing time, speed and pedestrian gap acceptance. The relevance of pedestrian gap acceptance of vehicle speed and positions were confirmed. Murai et al. (2017) also studied user behavior on a staggered crosswalk in Miyazaki, Japan. Criteria for the evaluation of safety and mobility in their study included calculation of PET (Pedestrian Encroachment Time), pedestrian delay, vehicle approach speed, position of yield cases when the pedestrian entered the crosswalk and jaywalk rate. They found that the mid-block crosswalk was safer with a longer PET, lower jaywalking rate and higher mobility with shorter pedestrian crossing time. However, details of driver behavior and comparison with ordinary mid-block crosswalks were not analyzed.

Overall, a concise but comprehensive analysis of both pedestrian and driver behaviors on different types of mid-block crosswalks is necessary to understand the effect of mid-block crosswalk design.

3. Study sites

In this study, a mid-block crosswalk in Yaizu City of Shizuoka Prefecture, Japan was selected. The subject unsignalized crosswalk is located in a segment of a two-way two-lane municipal road in front of the south exit of Yaizu railway station (Fig.1). In the middle of the roadway, there is a space with zebra pavement markings. Considering the pedestrian demand and the space necessary for placing a refuge island, this crosswalk is selected for the implementation.

The width of the roadway and lane are 10m and 3m, respectively. The width of the subject crosswalk is 4m and the crosswalk length is 11.7m measured on the central line of the crosswalk. The speed limit of this road is 40km/h. Entrances to a bus terminal and station plaza are located on the west side of the survey site, and a shopping street is located on the east side of the site. Most pedestrians on the crosswalk are train or bus passengers for commuting to

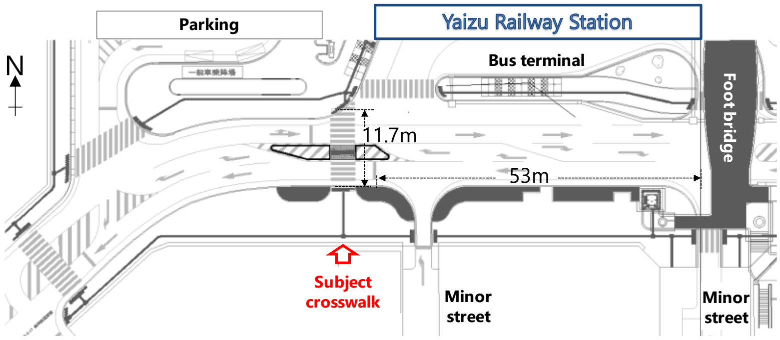


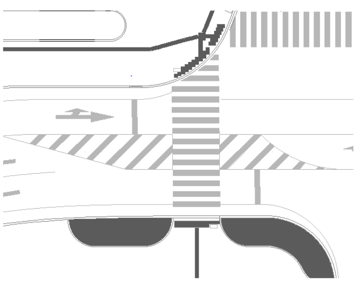
Fig. 1. Location of the subject crosswalk.

offices or schools, thus there is a considerable variation in traffic volume during the peak and off-peak hours. The trip purpose of traffic is mainly local short trips. In addition, there is another crosswalk located approximately 40m south from the crosswalk. However, the pedestrian volume on that crosswalk is extremely low. The westbound vehicles can make right-turn to the bus terminal immediately before the subject crosswalk. The eastbound vehicles which come from a curve go through or turn left to the bus terminal.

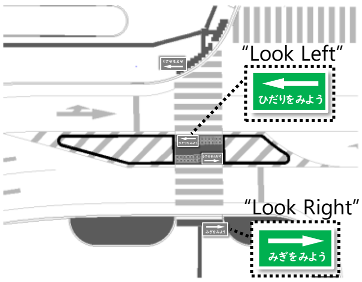
In the middle of cross-section of the road, there were zebra pavement markings until February 17, 2018 (Fig.2 (a)). By utilizing the space of the zebra markings, an improvement experiment of the refuge island on the mid-block crosswalk was conducted. The refuge island was implemented in the morning of February 17, 2018 as shown in Fig.2(b). The geometric layout of before and after cases are illustrated in Figs.2(c) and (d). The refuge island was formed by curbs and a green-colored sheet was stucked on the pavement surface with 2.5m width and 4m length inside the curb island. Additionally, two “look right” sheets and two “look left” sheets were stucked on the sidewalk and the refuge island, respectively, for guiding pedestrians to confirm the vehicle approaching directions.

(a) Before implementation (Photo)

(b) After implementation (Photo)



(c) Before implementation (Layout)



(d) After implementation (Layout)

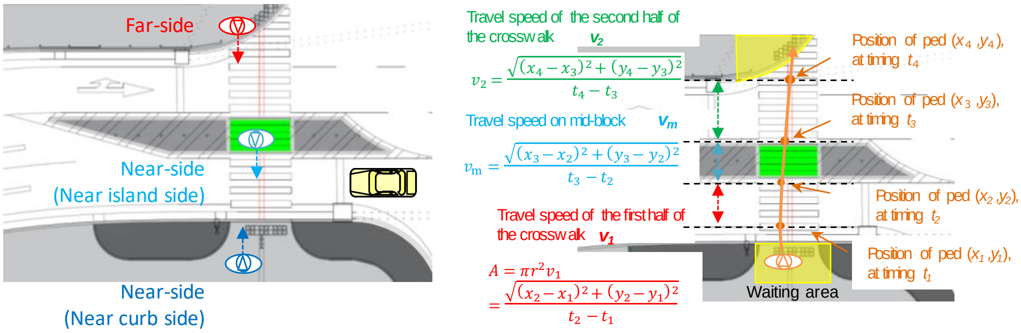
Fig. 2. Photo and layout of Crosswalk.

4. Methodology and data collection

4.1. Methodology

In the case of the conflicts between pedestrians and vehicles, the relative position between pedestrians and vehicles is an important factor. Here pedestrian position is defined as two main categories; near-side and far-side of vehicle. Near-side means the side where pedestrians and oncoming vehicles have conflict and far-side is the opposite side as shown in Fig.3 (a). In the near-side case, pedestrian position is further categorized into two groups: on the curbside and refuge island. The waiting areas of the pedestrian on the curbside are defined as 3m×2m areas in front of the crosswalk which are the yellow areas in Fig. 3 (b). When there is no other pedestrian on the waiting area and crosswalk, the pedestrian can be defined as a single pedestrian, otherwise the pedestrians are in a group.

The walking speeds are assumed to consist of three consecutive travel speeds v_1, v_m, and v_2 as shown in Fig. 3 (b). First-part speed v_1 and second-part speed v_2 are the travel speed in the first and second part of the crosswalk (m/sec), respectively. Mid-block speed v_m is the travel speed over the refuge island of mid-block crosswalk (m/sec). As for the comparison of v_1 and v_2, note that the first half for near-side pedestrians corresponds to the second half for far-side pedestrians, where pedestrians meet vehicles.



(a) Pedestrian positions (b) Pedestrian speeds

Fig. 3. Definitions.

In order to analyze the vehicle speed, vehicle approaching speed v_{app} is defined as a spot speed at a certain distance to the stop line. Particularly, the v_{app} when pedestrians enter the waiting area is important for understanding the driver yield behavior. In this study for simplification, it is assumed that when a pedestrian enters the waiting area, drivers will start to decide whether to yield to the pedestrian or not. Here, when the distance to stop line of approaching vehicles is less than 40m and the pedestrian has already entered the waiting area, yield behavior is defined that vehicles slowed down or completely stopped to give the way to pedestrians. Otherwise, it is a non-yield behavior. Yield rate can be calculated as the event number of yield cases divided by all the events.

Based on the results above, a binomial logit model is applied to estimate the vehicle yield probability when a pedestrian arrived near to the crosswalk. In the binomial logit model, the error term of utility to choose "yield" is assumed to follow the Gumbel distribution. The probability to yield is presented by Equation (1).

$$\Pr_i(yield) = \exp U_i/(1+\exp(U_i)) \tag{1}$$

$$U_i = \alpha_{i0} + \alpha_{i1} \times x_1 + \alpha_{i2} \times x_2 + \cdots + \alpha_{in} \times x_n \tag{2}$$

Where, U is the deterministic term of the utility to yield which is a linear function (Equation (2)) of several influencing factors, such as vehicle approaching speed, time to stop line, dummy variable of single pedestrian and dummy variable of vehicle position. The parameters of each variable are estimated using the maximum likelihood method.

4.2. Data collection

In order to analyze the pedestrian and driver behavior at crosswalks, video data was collected at the mid-block crosswalk before and after implementation of the refuge island. Table 1 presents the observation dates and the hourly traffic volumes of vehicles and pedestrians at the study sites.

Table 1. Hourly volumes of vehicles and pedestrians.

Site	Date	Observation Time	Northbound			Southbound			Westbound		Eastbound	
			PC	HV	MC	PC	HV	MC	Ped	Bic	Ped	Bic
Yaizu -before	02/13/2018 (Tue)	16:00-17:00	209	6	2	254	7	3	42	4	63	4
		17:00-18:00	259	8	3	215	10	4	44	5	95	10
	02/14/2018 (Wed)	7:00-8:00	211	7	9	310	9	4	171	6	47	1
		8:00-9:00	196	11	2	228	11	11	85	8	48	7
	Total		875	32	16	1007	37	22	342	23	253	22
Yaizu -after	03/13/2018 (Tue)	16:00-17:00	171	9	5	187	8	5	48	8	73	4
		17:00-18:00	225	7	6	227	9	1	68	8	67	11
	03/14/2018 (Wed)	7:00-8:00	185	6	5	235	7	7	160	7	62	1
		8:00-9:00	170	8	0	179	10	8	72	4	81	6
	Total		751	30	16	828	34	21	348	27	283	22

*PC: Passenger car, HV: Heavy vehicle, MC: Motorcycle, Ped: Pedestrian, Bic: Bicycle.
**Only southbound data of Yaizu were analyzed.

The trajectories of vehicles and pedestrians were extracted from video data by using the image processing system TrafficAnalyzer (2006). The position of each vehicle was extracted every 0.5sec and the positions of pedestrians were extracted at the edge of the waiting area, crosswalk and refuge island. The points where the front right wheels of vehicles and the feet of pedestrians are touching the ground are the reference observation points. Due to the video-recording angle limitations, the distance from stop line can only be covered for 45m for southbound of the crosswalk.

5. Comparison results of pedestrian and vehicle behaviors

5.1. Yield behavior analysis

Table 2 shows the yield rates of eastbound and westbound vehicles for the cases before and after implementation. Generally, the observation results showed very high yield rates which are approximately 80%, since the crosswalk is located in front of the station. Although there is a very small sample size observed on the refuge island, it is found that there is a 100% yield rate when pedestrians are on the refuge island and lower yield rate for near curbside. Drivers tend to pay more attention to the pedestrians on the refuge island. Pedestrians on the far-side have lower yield rate. It is because those pedestrians are still far away from approaching vehicles and there is a refuge island between them.

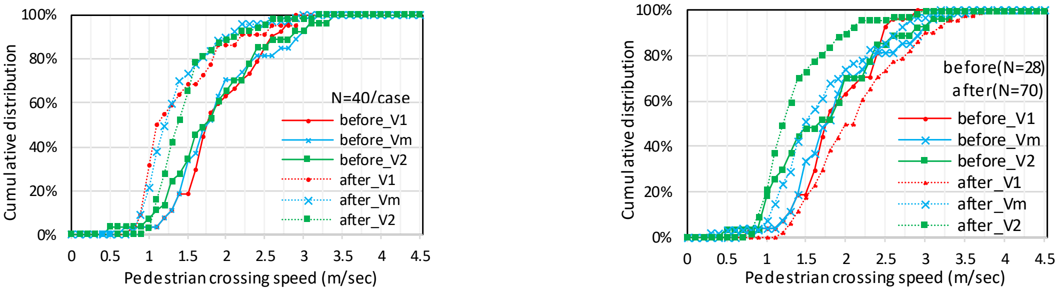
Table 2. Yield rate before and after implementation.

Yield rate % (Sample size)		Near-side (Curb side)	Near-side (Refuge island)	Far-side (Curb side)
Eastbound	Before	76.6 (77)	-	88.2 (110)
	After	84.8 (79)	100.0 (3)	88.7 (97)
Westbound	Before	84.4 (50)	-	82.0 (90)
	After	88.2 (62)	100.0 (3)	80.6 (76)

5.2. Pedestrian crossing speed

Pedestrian crossing speeds on first-part v_1, refuge island of mid-block crosswalk v_m and second-part v_2 are shown in Fig.4. Considering walking speed as a parameter for comparison of effects of implementing a refuge island, it was observed that the crossing speeds of pedestrians decreased after implementation when there are no vehicles existing from stop line to 30m upstream, as shown in Fig.4 (a). For example, at the 80th percentile, speeds reduced to an average of 1.5m/sec compared to 2.4m/sec before implementation. This decline of speed can suggest that the refuge island in the mid-block crosswalk gives the sense of security and safety to pedestrians. However, the tendency among v_1, v_2 and v_m is not clear for the cases without vehicles, since there is no approaching vehicle and other influence from surrounding conditions.

In the case of near curbside of vehicle (Fig.4 (b)), the decline in speed was observed as moving direction. For both of the before and after cases, v_1 (red lines) is the highest. The possible reason can be considered that pedestrians tended to increase their speed when vehicles yielded and gave way to them. Furthermore, v_1 of after case is higher than before case, so it can be concluded that pedestrians can easily increase their speed for a short distance after the implementation of the refuge island. However, for v_2 and v_m, the relationship is opposite with the speeds of the before case being higher. It can be considered that the crossing distance is divided into two parts by refuge island, after passing the conflicting part with vehicles, pedestrians feel safer after arriving on the refuge island.



(a) Without vehicle impact

(b) With vehicle impact

Fig. 4. Results of pedestrian crossing speeds.

5.3. Vehicle speed analysis

In this study, vehicle approaching speed by the distance to stop line is analyzed for two types of vehicles: passenger cars and heavy vehicles. In Fig.5, average approaching speeds of free flow vehicles which have no influence from pedestrians for the westbound vehicle are illustrated. At the stop line, the average speeds of passenger cars and heavy vehicles decreased by 2.3km/h and 5km/h, respectively after implementation. Comparing the two red lines, it is found that the passenger cars have lower approaching speed after implementation of a refuge island and there are more significant differences upstream of the stop line. Heavy vehicles (blue lines) have lower speed than passenger cars, however the amount of reduction after the implementation is more obvious than for the passenger cars.

Furthermore, the vehicle approaching speeds are also analyzed for the vehicles that are influenced by the pedestrians. It also shows the same declining trend after implementation.

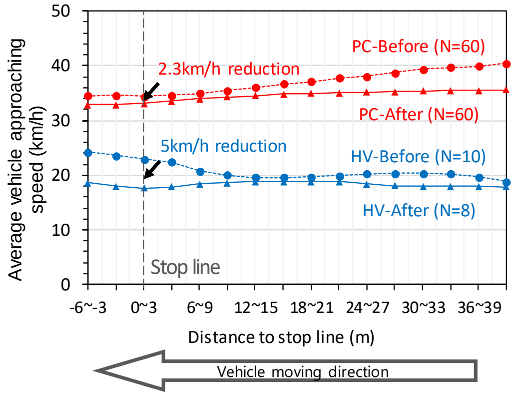


Fig. 5. Results of vehicle approaching speeds (Westbound). *PC: Passenger car; HV: Heavy vehicle.

6. Binary logit model of yield behavior

In order to understand the yield behavior of vehicles, two models are developed for the cases before and after implementation. The variables considered are vehicle approaching speed, time to stop line, dummy variable of single pedestrian and dummy variable of vehicle position.

For the crosswalk before implementation, vehicle approaching speed when pedestrians enter the waiting area (v_{app}) and dummy variable of pedestrian in single or group (d_{single}) influenced divers' decisions to yield to pedestrians. If the vehicles have high speed and the pedestrian who stands in the waiting area is a single pedestrian, the probability for drivers to yield to pedestrians is low. In contrast, if vehicles have low speeds and the pedestrians are in a group, drivers tend to yield to pedestrians.

In the case of after implementation, not only vehicle speed but also vehicle position have an impact on driver's yield behaviour, therefore the time to stop line for the vehicle (t) which can be derived by the two factors above were utilized. The longer the t, the higher the yield probability becomes. It is indicated that after the implementation of the refuge island, drivers also will pay attention to physical structure. Furthermore, it is found that the leading vehicles ($d_{leading}$) have a positive impact on the yield behavior, which means leading vehicles are more likely to yield to pedestrians.

Table 3.Binary logit models of yield behavior before and after implementation.

Model	Before	After
	Coef. (p-value)	
Const.	4.884 (0.000)	-1.697 (0.006)
Vehicle approaching speed (v_{app})	-0.1028 (0.000)	-
Time to stop line t= Distance to stop line / v_{app}	-	3.214 (0.000)
Dummy of single pedestrian d_{single} (single:1, group: 0)	-0.7768 (0.0860)	-
Dummy of vehicle position $d_{leading}$ (leading:1, following:0)	-	1.224 (0.012)
R^2	0.1169	0.2284
Hit ratio	81.23%	81.57%
Sample size	277	266

7. Conclusions

This study analyzed pedestrian and driver behavior using yield rate, pedestrian crossing speed and vehicle speed. A binary logit model for the yield rate was also developed based on the observed vehicle speed and position from the stop line.

For yield rate, the crosswalk in Yaizu has extremely high yield rates since the crosswalk is located in front of a train station. Vehicles had lower speeds after the implementation of the refuge island on the mid-block crosswalk, which indicates that the refuge island helps in controlling vehicle speed to improve pedestrian safety. Single pedestrians and leading vehicles will result in higher yield rate. After implementation of the refuge island, not only the vehicle speed but also the vehicle location had a strong impact on the yielding probability. It is indicated that the refuge island plays an important role on yield behavior. For the next step, the design of the refuge island such as the size and shape should be further analyzed.

The effects of pedestrian and vehicle volume, gender, age and so on were not analyzed in this paper, so it is necessary to analyze them in the future work. For further analysis, the impact of distance and speed on the yield behavior, and the delay of vehicles and pedestrians should also be discussed.

Acknowledgements

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