Analysis on Compliance Rate with the Yielding Rule to Pedestrians by Left-turning Vehicles at Signalized Intersections

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According to the *Japan Road Traffic Act*, left-turning vehicles (LTVs) must slow down so that they can immediately yield to the pedestrians walking on the crosswalks. However, in reality, a substantial proportion of vehicles pass in front of crossing pedestrians. The compliance rate (CR) with this rule affects the safety and efficiency of signalized intersections, which can be influenced by various factors such as crosswalk geometry, traffic volume and signal phasing patterns. Therefore, the objective of this study is to investigate the CR with the yielding rule to crossing pedestrians by LTVs at signalized intersections under different conditions. Both the number of LTVs that passed in front of pedestrians and complied with the rule are observed through video surveys. It was found that CR is influenced by LTV volume and radius of corner. Moreover, a linear regression model of CR was developed.

Key Words: *left-turning vehicles, pedestrian, compliance rate*

1. INTRODUCTION

At signalized intersections in Japan, there are many conflicts between left-turning vehicles (LTVs) and pedestrians since they usually share the same phase and same space. According to the *Road Traffic Act*[1)] in Japan, when approaching a crosswalk, vehicle must proceed at a speed that can stop immediately in front of the pedestrians ahead of the vehicle and may not pass in front of pedestrians. This means they should absolutely yield to the approaching/crossing pedestrians who are on the crosswalk. However, the phenomenon that vehicles pass in front of crossing pedestrians frequently occur, which means the compliance rate to the yielding rule is not 100%. It is obvious that capacity is strongly influenced but the method of capacity estimation in Highway Capacity Manual (HCM)[2)] and Japanese manual[3)] is not taking this situation into account.

Thus, the objective of this study is to investigate the compliance rate (CR) with the yielding rule to crossing pedestrians by LTVs at signalized intersections under intersection geometry, traffic volume and pedestrian crossing direction.

This paper is organized as follows: In the next section, existing literature on gap acceptance models, yielding behavior, method of capacity estimation and their differences from this study are presented. Then, the definition of CR and geometric conditions of the survey sites are introduced in section 3. In section 4, the basic information about data observation is introduced. Section 5 explained the model establishment. Finally, the last section summarizes this study's conclusions and proposes future directions.

2. LITERARURE REVIEW

In order to investigate the relationship between CR of left-turn lanes and its influencing factors, it is important to gain better insight into the method of analyzing the yielding behavior, gap acceptance model as well as the method of capacity estimation.

With regard to the gap acceptance behavior at signalized intersections, Alhajyaseen, et al.[4] developed the lag/gap acceptance model of LTVs considering the pedestrian crossing direction. However, the intersection geometry and signal timing were not considered.

In the case of unsignalized intersections, Zhao, et al.[5] established two models for vehicle yielding and pedestrian gap acceptance behaviors for a traffic simulation. In this study, the effects of the traffic and geometric factors on the operation of the unsignalized midblock crosswalks were discussed based on numerical experiments. Gorrini, et al.[6] analyzed the drivers' compliance with pedestrians right of way on zebra crossings and its relationship with influencing factors such as traffic volume. Sheykhfard, et al.[7] analyzed the observed conflicts occurred in unmarked and marked crosswalks, respectively. They built a model for driver yielding behavior using binary logistic regression.

Regarding the capacity estimation of left-turn lane, the existing guidelines or manuals consider the influence of pedestrian flows. For instance, Highway Capacity Manual (HCM)[2] (2016) and a Planning and Design of at-grade Intersections - Basic Edition; Guide for Planning, Design and Traffic Signal Control of Japan (Hereafter, JSTE manual)[3] (2018) considered the influence of pedestrians for estimating capacity of turning lanes. In these existing studies, only conflict area was considered when analyzing the interactions between pedestrians and vehicles. However, according to the act[1], the whole crosswalk should be analyzed.

3. CR ANALYSIS PROCEDURE

In order to calculate the CR of LTVs for each site, the number of LTVs which have interaction and conflict with pedestrian on the crosswalk are counted. On the study sites, it is observed that some of LTVs may stop once in front of crosswalk but the other LTVs pass the crosswalk without stopping. Thus, a decision line at 1m upstream (red line shown in **Fig.1**) in front of the crosswalk is defined. When LTVs are passing the decision line and cutting the path of some coming pedestrians, they are defined as the vehicle which did not comply with the yielding rule. In the case, LTVs stopped in front of crosswalk or slow down for yielding to pedestrians, which means LTVs do not pass the crosswalk in front of pedestrians, they are defined as the vehicles which complied with the yielding rule. Only the LTVs

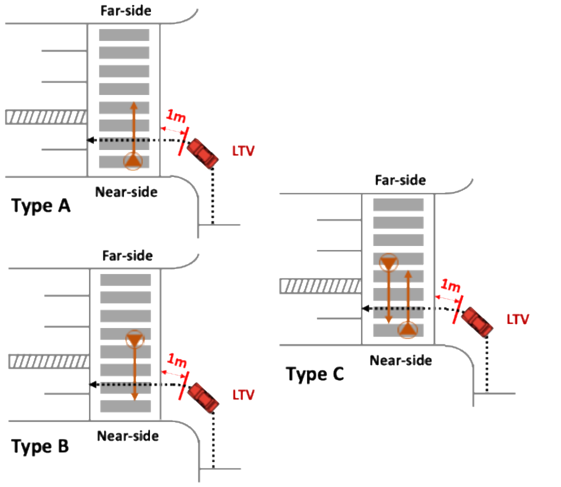

Fig.1 Types of interactions between pedestrians and left-turning vehicles

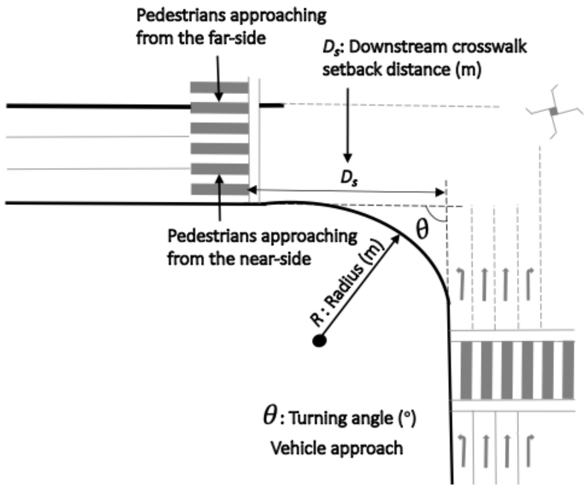

Fig.2 Definition of the parameters related to intersection layout

which have interactions with pedestrians are analyzed in this study. Furthermore, the interaction between LTV and pedestrian means that a LTV encounters the oncoming pedestrians who already entered in the crosswalk when passing the decision line.

The crossing pedestrians are categorized into two groups based on the crosswalk direction: near-side and far-side. The near-side pedestrian is the pedestrian coming from the side which is close to the LTVs, and the far-side pedestrian is those coming from the other side.

The interactions between pedestrians and vehicles are classified into three types as shown in **Fig.1**.

Type A: LTVs conflicting with near-side pedestrians,

Type B: LTVs conflicting with far-side pedestrians, and

Type C: LTVs conflicting with the both near-side and far-side pedestrians.

CR can be defined as the numbers of LTVs passing in front of oncoming pedestrians over the total number of LTVs which have interactions with

Table 1 Geometric characteristics of intersections and observing results

Intersection name	Position	Crosswalk geometry					Volume		No. of Vehicle cutting the path of Pedestrian		
		L (m)	D_s (m)	R (m)	θ (°)	Shared:1; Exclusive:0.	LTV (veh/h)	Ped. (ped/h)	Near	Far	Total
Heian-dori	south	16	16	3	128	1	17	119	0	1	1
	north	17	15	10	80	1	47	252	0	9	9
	west	23	12	12	75	1	27	224	0	2	2
Imaike	east	21	18	4	109	1	66	288	2	8	10
	north	21	19	2	91	1	49	192	0	8	8
	west	19	18	5	80	1	53	305	1	13	14
	east	21	18	4	109	1	64	250	1	6	7
	north	21	19	2	91	1	43	168	1	9	10
	west	19	18	5	80	1	49	310	0	13	13
Kanayama	east	15	7	13	95	1	50	543	2	5	7
	west	9	6	10	73	1	37	296	0	0	0
	north	37	13	10	76	0	37	936	3	4	7
	south	35	17	20	79	0	49	421	1	42	43
	north	37	13	10	76	0	39	618	0	0	0
Nishiosu	east	22	11	5	96	0	76	296	1	21	22
	west	25	9	14	87	0	94	277	5	17	22
	north	34	14	12	91	0	124	235	1	62	63
	east	22	11	5	96	0	56	465	0	15	15
	west	25	9	14	87	0	60	462	0	32	32
	north	34	14	12	91	0	82	382	0	25	25
Suemori-dori	south	17	8	5	77	1	57	147	2	8	10
	north	17	12	13	106	1	66	188	0	25	25
	east	25	13	17	57	1	43	100	0	9	9
	west	26	9	20	87	1	16	73	0	4	4
Hiroji-dori	north	8	5	8	91	1	26	156	0	0	0
	south	8	5	6	92	1	18	237	0	1	1
	west	16	9	6	98	1	12	66	0	0	0
Total									20	339	259

pedestrians. The CR of LTVs with near-side pedestrians is named as Near CR while the opposite direction is Far CR. When LTVs have conflicts with more than one pedestrian, the nearest one will be selected to calculate CR. Due to the limitation of samples, in this study the Type C is also counted as Type A and B depending on the crossing direction of the nearest pedestrian.

Regarding the intersection geometry, crosswalk length L, radius of corner R, turning angle θ and setback distance of crosswalk D_s were considered in this study and their definitions are illustrated in **Fig.2**.

4. FIELD OBSERVATIONS

In order to observe the CR, video recordings were carried out at several signalized intersections under various pedestrian volume and geometric conditions. Accordingly, user behaviors at twenty-seven crosswalks at six signalized intersections in Nagoya City were observed. Peak hours in the weekday were selected at most intersections. Both the number of LTVs that passed in front of pedestrians and yielded to pedestrians were observed.

Table 1 presents the geometric characteristics of observed sites and the number of LTVs which passing in front of crossing pedestrians at each approach. The observation sites have significantly different geometric layouts such as crosswalk length, radius of corner, turning angle and so on.

It is important to mention that all sites have a shared left-turn lane expect for two approaches in Kanayama and Nishiosu intersections which have an exclusive left-turn lane. At all observed sites pedestrians share the concurrent signal phase with the through and left-turning traffic in the parallel direction. Thus, LTVs has frequent conflicts with crossing pedestrians.

5. EMPIRICAL ANALYSIS AND REGRESSION MODEL

(1) Empirical analysis

a) Difference of CR between near-side and far-side

After observation, Near CR and Far CR were calculated for each crosswalk and the results are shown in **Fig.3.** It can be found that drivers were more compliant to near-side pedestrians which is close to 100%, compared to the far-side cases. A reasonable explanation is that far-side pedestrians are far away from LTVs, so that the LTVs are unwilling to slow down and wait for pedestrians to pass, thereby increasing their waiting time. This situation is particularly obvious when the crosswalk is long. Due to the limitation of the observed data, only the near-side pedestrian on the crosswalk were counted in this study. If the near-side pedestrians in the waiting area are also considered, the Near CR may have some reductions.

Since near CR is all close to 100% in the current database, the total CR which is similar to Far CR is not significantly affected. Therefore, the total CR is used for the following analysis.

b) Influence of different factors on CR

According to **Fig.3**, Far CR decreases with the increase of the crosswalk length, but Near CR shows no significant relationship with crosswalk length. The main reason why LTVs have lower CR when crosswalk gets longer is that the far-side pedestrians are still far from the LTVs even though they have entered the crosswalk. Thus, LTVs have enough time and space to cross.

The influence of LTV volume on the total CR showed a downward trends as shown in **Fig.4**. This is because the more LTVs, the higher probability as a following LTVs, then the longer potential waiting time because of the leading vehicles. If the leading LTVs yield to the pedestrians, especially for far-side pedestrians, then their waiting time will become longer. Therefore, when the following vehicles reach in front of crosswalk, they tend to select the gap of crossing pedestrians.

According to **Fig.5**, CR showed a negative trend with the radius of corner *R*. When *R* increases, the visibility of the driver is higher and it is easier to see pedestrians. In addition, the LTVs need to go further to reach the pedestrian on the crosswalk which means that they can have relatively higher speeds. This can make drivers more reluctant to slow down when they meet the crossing pedestrians.

(2) CR estimation model

In order to consider several factors influencing on the CR of LTVs, a linear regression model was tested to apply in this study. The final model was determined by the variables only that were significant at 95% confidence level and the model is shown in **Table 2**. According to the empirical analysis, both crosswalk length and the LTV volume can affect CR. However, there is a correlation between these two variables, and the influence of the LTV volume is more significant, thus LTV volume is selected in the

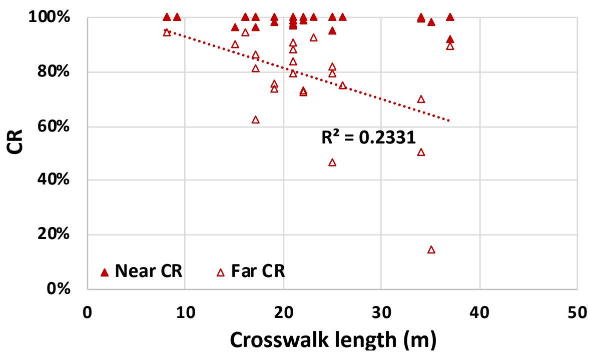

Fig.3 Difference between Near CR and Far CR and the relationship between CR and crosswalk length

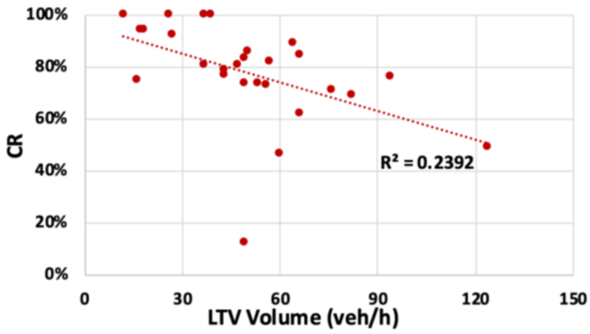

Fig.4 The influence of LTV volume on total CR

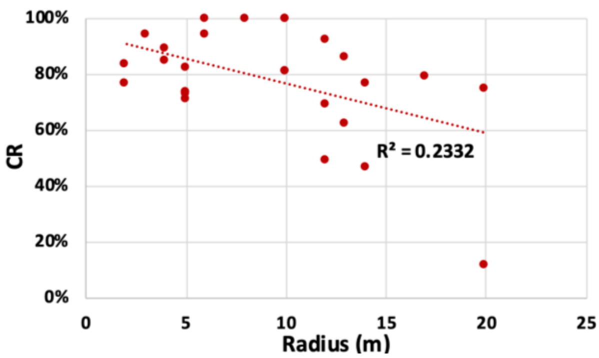

Fig.5 The influence of radius on total CR

model. The results of the model show that the LTV volume and radius have a negative impact on CR. This is due to the phenomenon of queuing vehicles. When the LTV demand is large, they tend not to comply the yielding rules to crossing pedestrians.

The dummy variables of shared/exclusive lane, median and cycle length were also considered when developing the CR model. Due to the same reason with crosswalk length that they have a correlation with each other, four combinations of these parameters were tested. As a result, the most significant set of parameters is used to build the model. Moreover, the compliance rate and the influencing factors have a non-linear relationship. Therefore, in the future work, the other non-linear function should be considered.

Furthermore, the accuracy was confirmed by comparing observed and estimated CRs as shown in

Fig.6. In addition, it is noticeable that there is 12.2% of CR (the left point shown in **Fig.6**) at the south approach of Kanayama intersection. Several reasons can be supposed for this. Firstly, the longer crosswalk length (*L*=35m) leads to a lower CR of the LTV for far-side pedestrians. Secondly, there is a high LTV demand with a low pedestrian demand which includes many pedestrians crossing from the far-side. This means that there are many conflicts between LTVs and far-side pedestrians, and vehicles can easily pass without deceleration. In addition, most LTVs chose the gap between the arriving time of near-side and far-side pedestrians to the conflict area. Although the length of another crosswalk at Kanayama intersection is also more than 30m, the LTVs in that approach are almost impossible to pass since there are a lot of pedestrians.

Table2 The regression model of P-CR and B-CR

Variable	Coefficient	Std. Error	P-value
Intercept	1.11	8.07×10^{-2}	0.00
LTV volume (veh/h)	-3.46×10^{-3}	1.17×10^{-3}	7.03×10^{-3}
Radius of corner (m)	-1.65×10^{-2}	5.67×10^{-3}	7.79×10^{-3}
R square	0.437		
MAPE	25.5%		

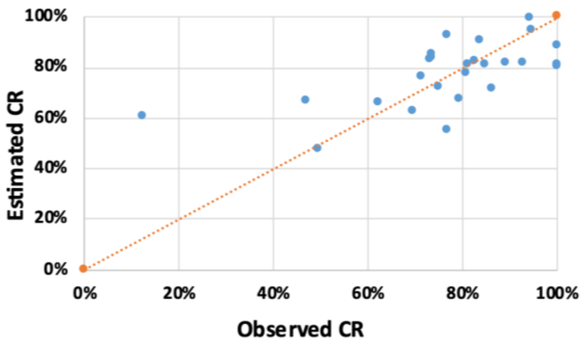

Fig.6 The CR estimation model

6. CONCLUSIONS AND FUTURE WORKS

This study investigated and modeled the compliance rate of LTVs. It was found that CRs of LTVs have a significant relationship with crosswalk length, radius, and LTV volume. On this basis, the CR of left-turn vehicles can be predicted through the intersection geometric conditions and left-turn vehicle volume, so as to reconsider the intersection design which can enhance the CR.

In addition, due to the lack of data and the correlation between those parameters, the significance of many parameters was not obvious. For example, fewer exclusive lanes were implemented at the intersections selected in this study. Therefore, in future work, other different types of intersections will be added for the further analysis.

In addition, this study only considered the pedestrians who already entered crosswalks. Pedestrians on the waiting area were not included in the analyses.

The non-linear function will be also considered in the future work to describe the relationship between CR and its influencing factors.

For the next step, the influence of pedestrians, signal timing and intersection geometry on the decision making for each driver of LTV will be analyzed by observing changes in positions and speeds for each movement.

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