Open Access

A Pilot Field Study of Influence of Restricted Sight Distances on Gap-Acceptance and Non-Gap-Acceptance RTOR Driving Behaviors

Xuedong Yan*[,1,2] and Stephen Richards[2]

[1]*MOE Key Laboratory for Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Shangyuancun, Haidian District, Beijing, 100044, P.R. China*

[2]*Southeastern Transportation Center (STC), The University of Tennessee, Suite 309, Conference Center Building, Knoxville, Tennessee 37996-4133, USA*

Abstract: Right turn on red (RTOR) is permitted at signalized intersection in the United States. Adequate intersection sight distances should be provided to ensure that the RTOR drivers turn into receiving lanes safely and efficiently. However, in practice it is not unusual to find signalized intersections with restricted right-turn sight distances, at which RTOR is still permitted. This research is focused on investigating if restricted right-turn sight distances have a significant impact on RTOR behaviors. A pilot field observation study was conducted at four signalized intersections: two with restricted right-turn sight distances and two with sufficient sight distances for 25 mph and 35 mph speed limits, respectively. Using a video camera, both gap-acceptance and non-gap-acceptance RTOR behavior data were collected at the intersections. In comparisons of RTOR behaviors at intersections with and without sight-distance problems, it was found that a restricted sight distance can cause drivers to seriously encroach into pedestrian crossings in order to maximize available sight distances at the intersections; lead to a higher non-stop RTOR violation rate; cause drivers to accept smaller gaps; and increase the possibility of conflicting with pedestrians. Due to these significantly negative effects on RTOR behaviors, traffic engineers are appealed to pay more attention to the right-turn sight distance issue at signalized intersections.

Keywords: Sight distance, RTOR, signalized intersections, gap acceptance, non gap acceptance traffic conflict, pedestrian safety.

INTRODUCTION

In the United States, right turn on red (RTOR) is a principle of law permitting drivers to turn right during a red signal at a signalized intersection. This policy can contribute to increasing intersection capacity, reducing auto pollution emissions and traffic delay, and saving energy [1]. On the other hand, RTOR can increase the crash risk because it leads to conflicts between right-turn vehicles and other vehicles and pedestrians crossing intersections [1, 2]. According to the prior research results, allowing RTOR can increase right-turn-related crashes by about 23%, pedestrian crashes by about 60%, and bicyclist crashes by about 100% [3]. It was reported that pedestrians and bicyclists who are approaching from the driver's right side are most likely to frequently have a conflict with RTOR drivers when they are looking left for a gap in traffic and fail to the pedestrian/bicyclist [4]. Additionally, right-turn drivers may stop beyond stop lines and block the pedestrian crosswalks, which can cause pedestrians to walk outside of designated crosswalks and increase crossing delay [5].

In most of States, traffic laws require drivers to stop at intersections and yield to approaching traffic before turning on red. However, based on the collection of observational data for more than 67,000 drivers at 110 intersections in Washington, D.C., Detroit, Dallas, and Austin, 56.9 percent of motorists fail to make a full stop at RTOR-allowed sites, and about 1 out of every 100 total right-turn vehicles is involved in an RTOR conflict [6]. Another observational research on RTOR indicated that 40% drivers fail to stop before turning right, about 30% drivers stop voluntarily, and about 30% drivers are forced to stop by traffic conditions before turning [7].

To improve intersection safety, MUTCD (2003) provides NO TURN ON RED sign to prohibit or restrict RTOR behaviors at intersections when applicable [8]. According to the MUTCD guideline (2003), a NO TURN ON RED sign should be considered when an engineering study indicates that one or more of the following conditions exists: 1) Inadequate sight distance to vehicles approaching from the left (or right, if applicable); 2) Geometrics or operational characteristics of the intersection that might result in unexpected conflicts; 3) An exclusive pedestrian phase; 4) An unacceptable number of pedestrian conflicts with right-turn-on-red maneuvers, especially involving children, older pedestrians, or persons with disabilities; and 5) More than three right-turn-on-red accidents reported in a 12-month period for the particular approach.

In the MUTCD guideline, inadequate right-turn sight distance is the primary factor for prohibiting or restricting RTOR behaviors. Nevertheless, in practice it is not unusual to find signalized intersections with inadequate right-turn

*Address correspondence to this author at the Southeastern Transportation Center (STC), The University of Tennessee, Suite 309, Conference Center Building, Knoxville, Tennessee 37996-4133, USA; Tel: (865) 974-0298; E-mail: xyan1@utk.edu

sight distances, which allow RTOR. The RTOR driver's eyesight can be restricted by static sight obstructions at intersection corners, such as crest curves of highways, trees, parked cars, slopes, walls, buildings, bridge piers, barriers, electricity poles, advertisement boards, etc. However, the impacts of sight distance on RTOR behaviors have not been investigated in previous studies yet. In this research, a pilot field observation study was conducted at four signalized intersections: two with restricted right-turn sight distances and two with sufficient sight distances for 25 mph and 35 mph speed limits, respectively. Both gap-acceptance and non-gap-acceptance RTOR behaviors were observed at the intersections using a video camera. The main objective of the study is to identify the significant changes of the RTOR behaviors associated with restricted right-turn sight distances.

BACKGROUND

For RTOR, the turning vehicle should completely stop at a red signal first, and if there are left-side oncoming vehicles crossing the intersection, the driver can accept proper gaps in the conflicting traffic to proceed with the right-turn maneuver. The gap-acceptance maneuvers are closely related to traffic safety and operation. The gap-acceptance decision has been used as an important measurement to analyze and predict traffic conflicts and accident rates at intersections [9-12].

Adequate intersection sight distances should be provided at intersections to ensure that the RTOR drivers when turning into receiving lanes will not unintentionally have conflicts/crashes with left-side oncoming vehicles. Procedures for determining appropriate intersection sight distances based on time gap acceptances are recommended by AASHTO (2004) according to various levels of intersection control and the maneuvers to be performed [13]. The required intersection sight distances are equal to the distances traversed by approaching vehicles at the design speeds during the critical time gap accepted by drivers. AASHTO presents six scenarios (A to F) in its design manual, where Case D is for intersections with traffic signal control. When RTOR is permitted at signalized intersections, it is equivalent to Case IIIC (right-turn sight distance for stop-controlled intersection). In the current AASHTO manual (2004), 6.5 sec is recommended as a critical gap accepted by right-turning passenger cars [13].

There are no previous studies that were focused on the impacts of sight distance on RTOR gap-acceptance behaviors. However, several studies on left-turn gap acceptance indicated that inadequate sight distances may cause those cautious drivers to reject physically adequate gaps because they need more time to make sure that the opposing-through lanes are clear, which can lead to needless delays for the left-turning traffic [14]; and the sight distance problem may lead to drivers' abnormal behaviors and conflicts with the opposing-through traffic [11, 12].

When RTOR drivers are approaching to the intersection, if there are no conflicting vehicles oncoming from left, their right turns at the intersection are non-gap-acceptance right-turn behaviors. Non-gap-acceptance RTOR is more likely to be observed during non-peak hours. In the non-gap-acceptance environments, it is reasonable to expect that the non stop violation rate is high because the perception of RTOR crash risk is low. However, drivers' attentiveness or alertness of conflicting with pedestrians might reduce as the non-stop rate increases.

RESEARCH METHOD

Site Selection

Four intersections that permit RTOR, located in the downtown area of Knoxville, Tennessee, were selected for this study. Two of them with 25 mph and 35 mph speed limits respectively have sufficient right-turn sight distances; in comparison, the other two with 25 mph and 35 mph speed limits respectively have limited sight distances. The air photos for the selected intersections are provided in Fig. (**1**), which illustrates observed right-turn lanes and sight obstructions.

For the 25 mph speed limit, the name of intersection without sight distance problem is Volunteer Blvd & Cumberland Ave (Fig. **1a**); and the name of intersection with sight distance problem is Locust St. and West Clinch Ave (Fig. **1b**), at which the right-turn sight distance is restricted by a parking garage at the intersection corner. The available sight distance at the intersection of Locust St. and West Clinch Ave is approximately 75 feet, much less than the required sight distance 240 ft for a 25 mph speed limit according to AASHTO. For the 35 mph speed limit, the name of intersection without sight distance problem is West Clinch Ave. & Henley St. (Fig. **1c**); and the name of intersection with sight distance problem is Eleventh St. & Western Ave. (Fig. **1d**), at which the right-turn sight distance is restricted by a tree and bushes at the intersection corner. The available sight distance at the intersection of Locust St. and West Clinch Ave is approximately 120 feet, much less than the required sight distance 335 ft for a 35 mph speed limit according to AASHTO.

Data Collection

A video camera was used to record the RTOR behaviors. The camera was positioned in the right side of the observed right-turn lane, which covered right-turn vehicle movement and signal change at the intersections. A total of 16 one-hour videos were filmed during weekdays. Four-hour videos were recorded for each intersection: two nonpeak hours (1:30 pm to 4:30 pm) and two peak hours (5:00 pm to 6:30 pm). Adobe Premiere Pro software was used to upload and compress the videos for computer storage in Window's WMV format. For recording gaps and vehicle positions, the video data collection methodology can produce higher quality traffic data than manual methods. With a video rate of 30 frames per second, the error caused by the video program is 0.03 sec for the event-times data. Due to the analyst's visual judgment error for vehicle positions, the total possible error for the event-times data could be up to 0.1 sec.

Data were collected only when the right-turn receiving lane was clear of traffic. Based on video observation and analysis, the right-turn behaviors were measured by the following variables:

For both gap-acceptance and non-gap-acceptance environments:

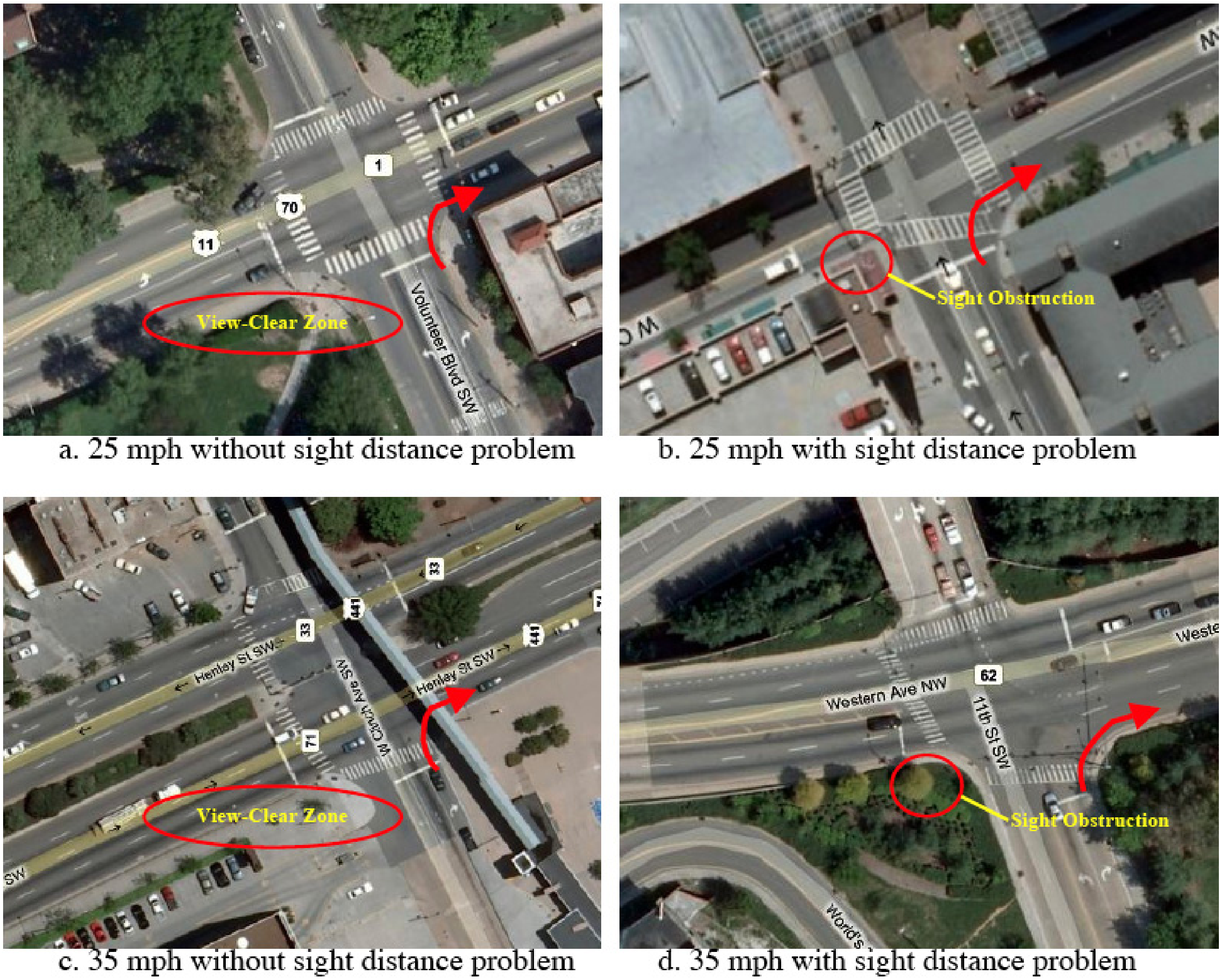


Fig. (1). Intersection layout.

- SPOSITION: When the driver completely stops at the intersection before turning, the right-turn vehicle's stop position relative to the stop line and pedestrian crossing is classified by three levels (0 = stop before stop line; 1 = stop beyond stop line and partially block pedestrian crossing; 2 = completely block pedestrian crossing);
- FOLLOW: Whether the right-turn vehicle is followed by another right-turn vehicle or not (Not = 0; Yes = 1);
- CONFLICT: Whether there is a conflict between the right-turn vehicle and pedestrians or coming-through vehicles during the turn (Not = 0; Yes = 1);
- SPEED: Intersection speed limit along the roadway which drivers turn into (0 = 25 mph; 1 = 35 mph)
- SIGHT: Whether the intersection has a right-turn sight-distance problem or not (Not = 0; Yes = 1);
- PEAK: Whether the video is recorded during a peak hour or nonpeak hour ((Nonpeak = 0; Peak = 1);

For gap-acceptance environments only:

- GAP (in s): The time headway between two coming-through vehicles which the right-turn driver may choose to turn. Note that this study did not distinguish between drivers' gap and lag acceptance/rejection. A lag is defined as the portion of a gap, measured from the moment at which the right-turn driver arrives at the stop line to the moment at which the oncoming vehicle passes the centerline of right-turn lane;
- ACC_REJ: Whether the driver accept or reject the gap (reject = 0; accept = 1);
- ADJ_VEH: Whether a vehicle(s) in the adjacent lane of right-turn receiving lane is coming along with a gap (No = 0; Yes = 1). The oncoming vehicles adjacent to the receiving lane may affect drivers' judgments of gap size;

For non-gap-acceptance environments only:

- STOP: Whether the driver completely stops at the intersection before turning (Not = 0; Yes = 1).

- TURN: Whether the driver turns or not when it should be safe to make a right turn on right (Not = 0; Yes = 1).

When RTOR is "shadowed" by a protected left-turn signal on the cross street, RTOR movements can be completed without any concern for cross street gaps in traffic [15]. In this study data were not recorded when RTOR was "shadowed" by a protected left-turn signal on the cross street, or when RTOR was conflicting with the opposing protected left-turn movement. The reason is that in both cases, the right-turn sign distance has no significant influence on RTOR; and if the two cases were included in data collection and analyses, they would distract the research object in this study.

OBSERVATION RESULTS AND DATA ANALYSES

Gap-Acceptance RTOR

Table **1** lists the descriptive statistics for 490 individual gap decisions from a total of 68 right-turn movements, including 30 observations without sight distance problem and 38 observations with sight distance problem. A one-way ANOVA (analysis of variance) was used to investigate differences between factors in rejected and accepted gaps. The ANOVA results show that both rejected and accepted gaps are not statistically different in most comparisons of different variable levels, except that the average accepted gap (9.46 sec) at the 35 mph intersections are longer than that (6.79 sec) at the 25 mph intersections ($p < 0.001$). However, this result does not necessarily imply that drivers would be more likely to accept larger gaps at the higher speed-limit intersections because the difference in accepted gap may result from the different gap (traffic) distributions between the intersections.

The logistic regression (logit) technique [16] can be used to estimate the probability that an event (such as the acceptance of a gap) will or will not occur, which has been widely applied in gap acceptance research [11, 12, 17, 18]. The basic logistic regression model is shown in Equation 1.

$$P = \frac{e^{g(x)}}{1+e^{g(x)}} \quad (1)$$

The logit of the multiple logistic regression model (Link Function) is given by Equation 2:

$$g(x) = \ln\left[\frac{P}{1-P}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_n x_n \quad (2)$$

where P is the probability the right-turn driver accepts a gap or not (ACC_REJ), and x_n are independent variables. The

Table 1. Descriptive Statistics for Rejected and Accepted Gaps

ACC_REJ	Variable	Level	N	Mean	S.D.	S.E.	95% C.I.		One-Way ANOVA	
							L.B.	U.B.	F	Sig.
Reject	SIGHT	No	250	3.67	1.96	0.12	3.43	3.91	0.237	0.626
		Yes	172	3.58	1.70	0.13	3.32	3.84		
	SPEED	25 mph	168	3.83	1.85	0.14	3.55	4.11	3.219	0.073
		35 mph	254	3.50	1.85	0.12	3.27	3.73		
	PEAK	No	180	3.56	2.01	0.15	3.27	3.86	0.480	0.489
		Yes	242	3.69	1.73	0.11	3.47	3.91		
	FOLLOW	No	24	8.96	3.01	0.61	7.69	10.23	0.340	0.560
		Yes	44	7.79	3.17	0.48	6.83	8.76		
	ADJ_VEH	No	100	3.46	1.51	0.15	3.16	3.76	1.904	0.169
		Yes	191	3.77	1.95	0.14	3.49	4.05		
	Total		422	3.63	1.86	0.09	3.46	3.81		
Accept	SIGHT	No	30	7.80	3.52	0.64	6.48	9.11	0.915	0.342
		Yes	38	8.53	2.82	0.46	7.61	9.46		
	SPEED	25 mph	32	6.79	2.36	0.42	5.94	7.64	14.731	0.000
		35 mph	36	9.46	3.24	0.54	8.37	10.56		
	PEAK	No	24	8.96	3.01	0.61	7.69	10.23	2.187	0.144
		Yes	44	7.79	3.17	0.48	6.83	8.76		
	FOLLOW	No	30	7.87	2.81	0.51	6.82	8.92	0.615	0.436
		Yes	38	8.47	3.40	0.55	7.36	9.59		
	ADJ_VEH	No	13	8.50	2.73	0.76	6.85	10.15	0.015	0.904
		Yes	33	8.37	3.51	0.61	7.12	9.61		
	Total		68	8.21	3.14	0.38	7.45	8.97		

independent variables can be either categorical (including SIGHT, SPEED, PEAK, FOLLOW, and ADJ_VEH) or continuous (GAP). Both main effects and interactions can be accommodated in logistic regression.

Using logistic regression to fit the right-turn gap acceptance data, it was found that GAP, SIGHT, FOLLOW, and interaction between GAP and SIGHT are significant at a 0.05 significance level. The modeling results are shown in Table **2**. Additionally, ADJ_VEH and interaction between GAP and ADJ_VEH are marginally significant at a 0.1 significance level, which might be identified as important predictors if more gap-acceptance data are available for modeling.

Table 2. Logistic Regression Modeling Results for Right-Turn Gap Acceptance

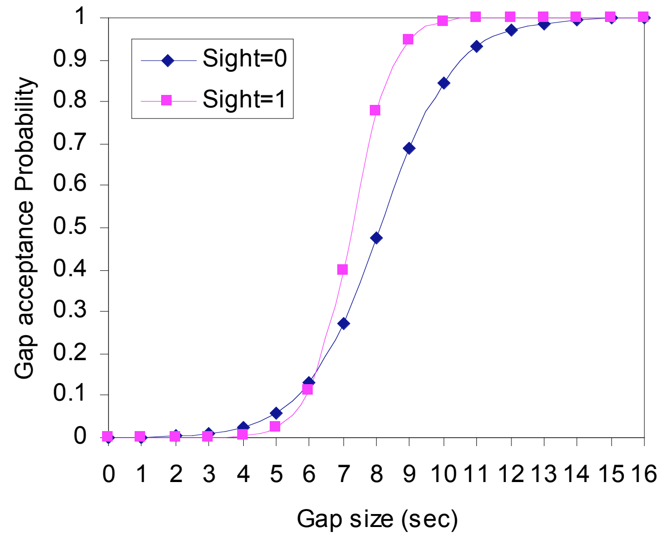
Independent Variable	B	S.E.	Wald	DF	Sig.
Constant	-7.264	1.633	19.780	1	.000
GAP	.896	.255	12.338	1	.000
SIGHT	-4.787	2.139	5.010	1	.025
FOLLOW	1.041	.455	5.229	1	.022
ADJ_VEH	2.826	1.678	2.837	1	.092
GAP* SIGHT	.767	.333	5.299	1	.021
GAP* ADJ_VEH	-.489	.270	3.289	1	.070

Model Summary:
2 Log likelihood = 209.196
Cox & Snell R Square = 0.322
Nagelkerke R Square = 0.538

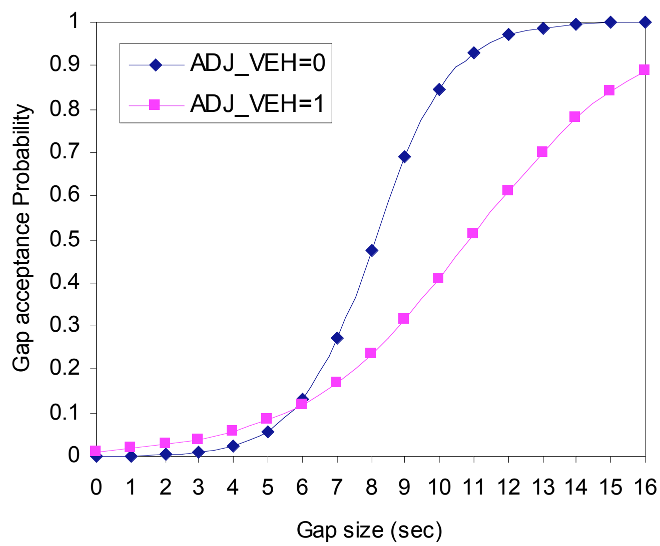
Fig. (**2a**) illustrates the effect of sight distance on right turn gap acceptance without considering other factors. It shows that the larger the available gaps, the higher the probability that drivers will accept the gaps. However, as the gap size increases, the same size gaps are more likely to be accepted by drivers at the intersections with sight distance problems, compared to those at the intersections without sight distance problems. One possible explanation for this trend is that since drivers with sight distance problems may not see the oncoming vehicles in gaps, they tend to accept the gaps assuming that the gaps would be large enough to turn into safely.

Fig. (**2b**) illustrates the potential effect of adjacent vehicles in the oncoming traffic on right-turn gap acceptance without considering other factors. It shows that when there are vehicles appearing in the adjacent lane that drivers intend to turn into, they may cause drivers to accept larger gap. Although the result seems intuitively reasonable, this effect is only marginally significant, which needs to be proved in further research when a larger sample is available.

The modeling results also indicate that, when the right-turning vehicles are followed by another vehicle in the right-turn lanes, the drivers are more likely to accept smaller gaps, compared to those without following vehicles. It is probably because the right-turning drivers are not willing to cause the unnecessary delay to other drivers.



a. Effect of sight distance without considering other factors



b. Effect of adjacent vehicles in the oncoming traffic without considering other factors

Fig. (2). Predicted probability that drivers accept gaps to make right turns.

Additionally, the analysis of drivers' stop positions at the right-turn lanes shows that more than 90% drivers completely blocked pedestrian crossings at the intersections with sight-distance problems, as shown in Fig. (**3**). The percentage is much higher that at the intersections without sight-distance problem (57%). It is because drivers tend to stop as forward as possible to maximize their available sight distances at the intersections with sight obstructions. This result indicates that the sight distance problem can cause pedestrians to walk outside of designated crosswalks and increase crossing delay.

Non-Gap-Acceptance RTOR

In non-gap-acceptance environments, a safe and efficient RTOR action should be: first, stopping at the stop line completely; secondly screening the left to ensure intersection approach is clear and checking if there are conflicting pedestrian movements; then, starting the right-turn maneuver

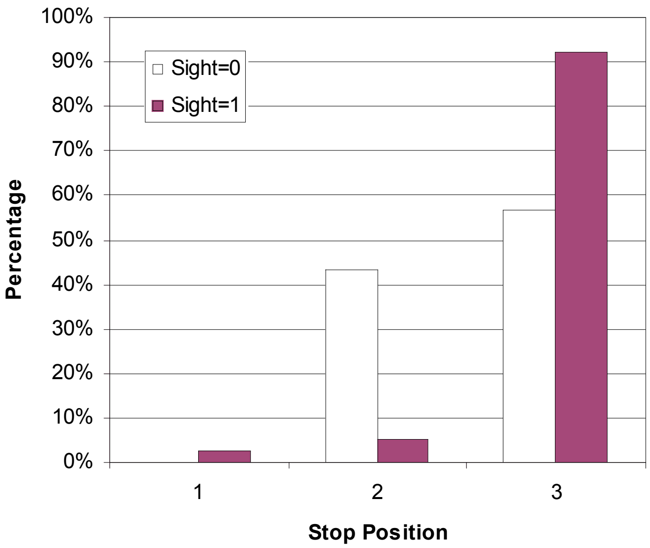


Fig. (3). Full-stop drivers' stop position distribution in gap-acceptance environments (Note: 0 = stop before stop line; 1 = stop beyond stop line and partially block pedestrian crossing; 2 = completely block pedestrian crossing).

safely. In this study, three categorical dependent variables STOP, TURN, and CONFLICT are used to investigate the driver's safety and efficiency of RTOR operation. Table **3** lists the descriptive statistics of the three dependent variables corresponding to the independent variables for a total of 517 non-gap-acceptance RTOR behaviors. Chi-square tests were used investigate if there are significant relationships between the categorical variables.

It is found that the right-turn sight distance (SIGHT) significantly affect the driver's non-gap-acceptance RTOR behaviors. Compared to the intersections without sight-distance problem, the non-stop right-turn violation rates are much higher at the intersections with sight-distance problems (72.7% *vs* 41.7%; Chi-Square test: $p < 0.001$). The reason is that when drivers' sights were restricted at the intersections, they tend to rolling forward slowly to maximize their right-turn sight distances; and once they found there were no vehicles from the left, they would continuously finish the turn maneuvers. This analysis is also supported by the drivers stop position observations. Fig. (**4**) shows that more than 80% drivers completely blocked pedestrian crossing at the intersections with sight-distance problems. The percentage is significantly higher that at the intersections without sight-distance problem (54%). The result is consistent with the observations of stop positions in the gap-acceptance environments. Another interesting finding is that insufficient sight distances can lead to more no-turn behaviors (8.5% *vs* 3.4%; Chi-Square test: $p = 0.016$) and conflicts with pedestrians (2.8% *vs* 0.4%; Chi-Square test: $p = 0.037$). When drivers' sights are restricted at the intersections, those conservative drives are more likely to refuse RTOR in order to avoid a potential risk of collision with an unseen oncoming vehicle. On the other hand, the sight-distance problem can increase drivers' attentions on the

Table 3. Descriptive Statistics of Non-Gap-Acceptance RTOR Behaviors

			STOP			TURN			CONFLICT			Total
			No	Yes	Chi-Sqr Tests	No	Yes	Chi-Sqr Tests	No	Yes	Chi-Sqr Tests	
SIGHT	No	Count	98	137	<0.001	8	227	0.016	234	1	0.037	235
		%	41.7	58.3		3.4	96.6		99.6	0.4		100
	Yes	Count	205	77		24	258		274	8		282
		%	72.7	27.3		8.5	91.5		97.2	2.8		100
SPEED	No	Count	146	97	0.521	6	237	0.001	236	7	0.062	243
		%	60.1	39.9		2.5	97.5		97.1	2.9		100
	Yes	Count	157	117		26	248		272	2		274
		%	57.3	42.7		9.5	90.5		99.3	0.7		100
PEAK	No	Count	138	104	0.493	13	229	0.469	237	5	0.596	242
		%	57	43		5.4	94.6		97.9	2.1		100
	Yes	Count	165	110		19	256		271	4		275
		%	60	40		6.9	93.1		98.5	1.5		100
FOLLOW	No	Count	211	119	0.001	11	319	<0.001	321	9	0.023	330
		%	63.9	36.1		3.3	96.7		97.3	2.7		100
	Yes	Count	92	95		21	166		187	0		187
		%	49.2	50.8		11.2	88.8		100	0		100
Total		Count	303	214		32	485		508	9		517
		%	58.6	41.4		6.2	93.8		98.3	1.7		100
			100	100		100	100		100	100		100

left intersection approach so as to distract their attentions on pedestrian movements. Thus, it results in a higher probability of conflicts with pedestrians during RTOR. Additionally, the intersection speed limit can also significantly affect the no-turn behavior. Compared to the 25 mph speed limit, drivers are more likely to refuse RTOR at the intersections with 35 mph speed limits (9.5% *vs* 2.5%; Chi-Square test: $p = 0.001$). A possible explanation is that drivers tend to be more conservative at the higher speed intersections.

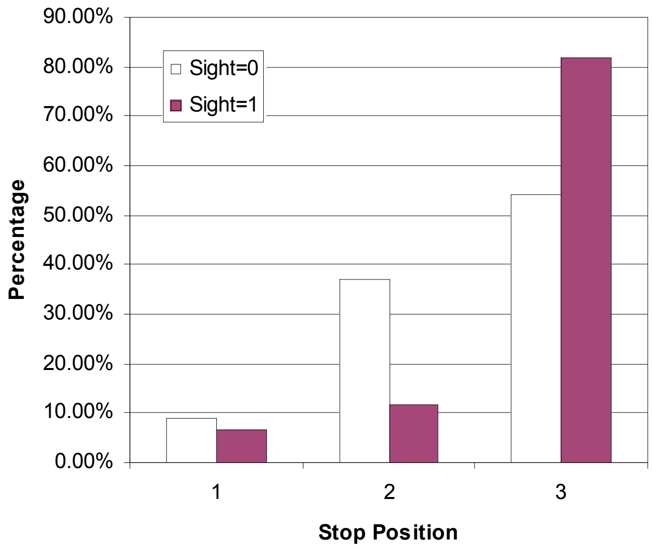


Fig. (4). Full-stop drivers' stop position distribution in non-gap-acceptance environments (Note: 0 = stop before stop line; 1 = stop beyond stop line and partially block pedestrian crossing; 2 = completely block pedestrian crossing).

As shown in Table **3**, FOLLOW also significantly influences the RTOR operation. When the RTOR drivers were followed by other vehicles in the right-turn lanes, they are more likely to stop completely (50.8% *vs* 36.1%; Chi-Square test: $p = 0.001$) and refuse RTOR (11.2% *vs* 3.3%; Chi-Square test: $p < 0.001$), and less likely to involve conflicts with pedestrians (0.0% *vs* 2.7%; Chi-Square test: $p < 0.001$), compared to the situation where there are no following vehicles. These results imply that the following vehicles increase RTOR drivers' safety awareness, especially at the intersections with sight-distance problems.

CONCLUSIONS AND DISCUSSIONS

This field observation study for RTOR driving behaviors in both gap-acceptance and non-gap-acceptance environments confirmed the negative effects of a sight distance problem on traffic operation efficiency and safety. The negative effects include that:

- When drivers intend to turn right on red at intersections, a restricted sight distance can cause drivers to seriously encroach into pedestrian crossings in order to maximize available sight distances. Such a behavior would lead to potential conflicts with pedestrians and pedestrian-crossing delay.
- A sight-distance problem can lead to a higher non-stop RTOR violation rate.
- When drivers try to accept gaps to make right turns on red, the sight distance problem can cause drivers to accept smaller gaps since drivers may not see the oncoming vehicles in the gaps. In this case, if an unseen oncoming vehicle in a blind area caused by a sight obstruction is seriously speeding, it may lead to a crash risk with the right-turning vehicle.
- The observation results displayed that RTOR driving behaviors under limited sight-distance conditions can significantly increase the possibility of conflicting with pedestrians in non-gap-acceptance environments.

RTOR driving behaviors are also found to be significantly associated with other factors. Drivers are more likely to refuse RTOR at intersections with higher speed limits; and when a right-turning vehicle is followed by the other vehicles behind, RTOR drivers show a higher level of safety awareness.

Limited by the pilot experiment scale, only four intersections are selected for this filed study. The observation results are not suggested to be used for prediction of RTOR behaviors under different intersection conditions. However, since the traffic and geographic environments are similar between the intersections with and without sight distance problems, this research clearly illustrated the tendency that poor intersection visibility can seriously result in RTOR operation and safety problems. The analyses in this paper contribute to a better understanding of the relationship between intersection visibility and traffic safety and operation.

Based on this pilot study, it is suggested to collect larger sample-size data of gap-acceptance and non-gap-acceptance behaviors as well as traffic conflicts associated with RTOR at more intersections. If driving simulators are available, more behavior-related parameters, such as speed, deceleration/acceleration rates, turn maneuvers, response time, and driver's eye movements can be collected to comprehensively and deeply analyze the changes in the driving behaviors associated with available (sufficient *vs* insufficient) sight distance at intersections. In addition, if available sight distance is an available variable in any crash databases, it is strongly suggested to quantify the relationship between crash risk and sight distance problem. These further studies can greatly contribute to guiding proper use of the NO TURN ON RED SIGN according to the extent of sight-distance restriction.

ACKNOWLEDGEMENTS

The authors would like to acknowledge supports of Beijing Jiaotiong University Fund (2010RC003) and the Fundamental Research Funds for the Central Universities (2009JBZ012-3) from China.

REFERENCE

[1] W. D. Wagoner, "Driver behavior at right-turn-on-red locations", *ITE Journal*, vol. 62, pp. 18-20, 1992.

[2] G. Abu-Lebdeh, R. F. Benekohal, and B. Al-Omari, "Models for right-turn-on-red and their effects on intersection delay", *Transport. Research Record,* vol. 1572, pp. 131-139, 1997.

[3] P. L. Zador, "Right-turn-on-red laws and motor vehicle crashes*:* A review of the literature", *Accident Analysis & Prevention*, vol. 16, pp. 241-245, 1984.

[4] D. F. Preusser, W. A. Leaf, K. B. DeBartolo, and R. D. Blomberg, "The effect of right-turn-on-red on pedestrian and bicyclist

accidents", Department of Transportation, Washington, DC, USA Report HS-806-182, 1981.

[5] R. A. Retting, M. S. Nitzburg, C. M. Farmer, and R. L. Knoblauch, "Field evaluation of two methods for restricting right turn on red to promote pedestrian safety", *ITE Journal*, vol. 72 , pp. 32-35, 2002.

[6] C. V. Zegeer and M. J. Cynecki, "Determination of motorist violations and pedestrian-related countermeasures related to right-turn-on-red", *Transport Research Record*, vol. 1010, pp.16-28, 1985.

[7] ITE Technical Council Committee 4M-20, "Driver behavior at right-turn-on-red locations", *ITE Journal*, vol. 62, pp. 18-20, 1992.

[8] Federal Highway Administration, *Manual of Uniform Traffic Control Devices (MUTCD)*, Federal Highway Administration, 2003.

[9] A. C. E. Spek, P. A. Wieringa, and W. H. Janssen, "Intersection approach speed and accident probability", *Transportation Research Part F: Traffic Psychology and Behavior*, vol. 9, pp. 155-171, 2006.

[10] J. Alexander, P. Barham, and I. Black, "Factors influencing the probability of an incident at a junction: results from an interactive driving simulator", *Accident Analysis & Prevention*, vol. 34, pp. 779-792, 2002.

[11] X. Yan, and E. Radwan, "Influence of restricted sight distances on unprotected left-turn operation at signalized intersections", *Journal of Transportation Engineering*, vol. 134, pp. 68-76, 2008.

[12] X. Yan, and E. Radwan, "Effect of restricted sight distances on driver behaviors during permitted left-turn phase at signalized intersections", *Journal of the Transportation Research Part F: Traffic Psychology and Behavior*, vol. 10, pp. 330-344, 2007.

[13] American Association of State Highway and Transportation Officials (AASHTO), *A Policy on geometric design of highways and streets*, Transportation Research Board, 2001

[14] M. S. Tarawneh and P. T. McCoy, "Effect of offset between opposing left-turn lanes on driver performance", *Transportation Research Record* vol 1523, pp. 61-72, 1996.

[15] K. K. Dixon, J. L. Hibbard, and H. Nyman, *Right-Turn Treatment for Signalized Intersections*", Urban Street Symposium in Dallas, 2000.

[16] A. Agresti, "*An Introduction to Categorical Data Analysis*". John Wiley and Sons, Inc., 1996.

[17] M. Abou-Henaidy, S. Teply, and J. D. Hunt, "Gap acceptance investigations in canada", *in Second International Symposium on Highway Capacity*, 1994. vol. 1, pp. 1-20, 1994.

[18] K. Fitzpatrick, "Gaps accepted at stop-controlled intersections", *Transportation Research Record,* vol. 1303, pp 103-112, 1991.

Received: September 20, 2009 Revised: October 10, 2009 Accepted: October 11, 2009