An Analysis of the Effects of Simple Traffic Safety Measures at a Signalized Intersection: Before-and-after Study on Right-Turn Behavior

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Abstract: Recently, simple traffic safety measures such as road markings, warning signs or color pavement which mainly aim to promote drivers' awareness have been implemented. These measures are inexpensive, thus can relatively easily be implemented. However, the effects on safety are not clear since these measures do not affect driving behavior directory. This study analyzes the effects of the simple traffic safety measures on driving behavior through a before-and-after survey at a signalized intersection where frequent right-turn-straight-run (RTSR) accidents had occurred. It was indicated that the right-turn vehicles tended to follow the intention of the guide of right-turn-start-position after the implementation. Also, by comparing the gap acceptance behavior, the judgment of gap acceptance did not only shift to safe side after the implementation, but also become more efficient long period after the implementation.

Keywords: Traffic Safety, Before-and-after Study, Right Turn, Gap Acceptance

1. INTRODUCTION

Traffic accident has been a serious social problem in today's automobile-dependent society. In Japan, the number of traffic fatalities has decreased annually, and been under 5,000 people since 2009. However, the number of casualties which consists of fatalities and injuries records almost 900,000 people in 2011 (White Paper, 2012), which should still be a matter of concern. Especially, around 15% of all accidents were occurred at signalized intersections. At signalized intersections, right-turn-straight-run (RTSR) accidents (with left-hand traffic) are one of the main accident types and the second biggest killer after the nose-to-nose accidents. Thus, urgent and effective countermeasures to the RTSR accidents are required.

Recently, on the other hand, simple traffic safety measures such as road markings, warning signs or color pavement which mainly aim to promote drivers' awareness have been implemented. These measures can relatively easily be implemented due to the lower installation cost. However, the effects on safety are not clear since they affect only the drivers' awareness, rather than driving behavior directory.

In order to implement the efficient and effective safety measures with limited resources, the scientific and objective evaluations of the measures are important. Many traffic safety measures have usually been evaluated on the basis of the decrease (or increase) of the number of traffic accidents before and after implementing the measures. In order to compare the number of traffic accidents, however, the long-period collection of traffic accident data is required because traffic accidents are rare phenomenon. Thus, there are some difficulties that the speedy follow-up cannot be conducted. Also, low number of traffic accidents does not necessarily mean safe if there are frequent danger behavior or near-miss. On the other hand, it is useful for follow-up of traffic safety measures to compare driving behavior of drivers before and after implementing the measures, i.e. before-and-after study.

The objective of this study is to analyze the effects of the simple traffic safety measures on right-turn behavior through a before-and-after survey at a signalized intersection where frequent RTSR accidents had occurred and some simple measures such as red color pavement were implemented. Especially the effect of the modified pavement marking on gap acceptance behavior is mainly focused on.

2. PREVIOUS STUDIES

There have been some studies which examine the effects of simple traffic safety measures promoting the drivers' awareness. Xuedong et al. (2009) conducted a simulator-based study that was designed to examine the effect of the pavement marking countermeasure, stating "Signal Ahead", on driving behavior with regard to the dilemma zone at signalized intersections, and found that the marking can reduced the probabilities of both conservative-stop and risky-go decisions, red-running rate, and deceleration rate for stopping drivers at higher speed limit intersections. Charlton (2007) analyzed the effects of advance warning signs and road markings which warn of horizontal curves on driving behavior, based on the driving simulator experiments. It was found in the study that only the advance warning signs suggesting the presence of curves could not be as effective at reducing speeds as using the combination of the warning signs and the chevron sight boards and/or repeater arrows. It was also shown that the herringbones road marking was effective for lane position keeping of drivers. Jørgensen and Wentzel-Larsen (1999) developed a theoretical model of driving behavior that was designed to analyze the effects of warning sign installations on drivers' speed selection, expected objective accident costs, and total driving cost, focusing on a certain stretch of road.

Although there may be some important things related to the RTSR accidents, such as conflict point analysis, the gap acceptance behavior will be most important. Chovan et al. (1994) showed that incorrect gap acceptance may lead to roughly 30% of left-turn accidents with right-hand traffic. The gap acceptance decision has been used as an important factor to predict traffic conflicts and accident rates at intersections (Alexander et al., 2002; Spek et al., 2006).

In Alhajyaseen et al. (2013), the concept of considering general gap acceptance behavior (i.e. not only for specific situation) were divided into two types. One of them models the gap acceptance behavior by deterministic concept, called "deterministic models", whereas another one models the gap acceptance behavior by probabilistic concept, called "probabilistic models". The deterministic models use a constant critical gap calibrated for local conditions and assume the drivers as consistent population, which accept if the gap is greater than the critical gap and reject if the gap is smaller than the critical gap (Troutbeck and Brillon, 2002). On the other hand, the Logit model (Ben-Akiva and Lerman, 1985) or the Probit model (Mahmassani and Sheffi, 1981) are used for the probabilistic gap acceptance models, where the drivers are assumed to be inconsistent population and the probability of gap acceptance are defined for each size of gaps. The probabilistic model can be likely in real situations.

While many studies have focused on the right-turn gap acceptance behavior at unsignalized situation (e.g. Alexander et al, 2002; Cooper and Zheng, 2002; Yan et al, 2007), there have been few studies analyzing the right-turn gap acceptance behavior at signalized intersections. Mori et al. (1996) developed a probabilistic gap acceptance model of right-turning vehicles (with left-hand traffic) at signalized intersections based on field observation survey. And, they found that the gap acceptance behavior depends on not only the gap sizes but also the other factors such as right-turn waiting time especially when the gap sizes are around the critical ones. Yan and Radwan (2007a) analyzed, by using field observation survey, the left-turn (with right-hand traffic) gap acceptance behavior at signalized intersections affected by the restricted sight distances due to the opposing turning vehicles, and found that the sight obstruction may increases the size of gaps accepted by the right-turn vehicles and thus increases follow-up time. However, there is no previous study analyzing the effects of simple traffic safety measures such as color pavement on the right-turn gap acceptance behavior.

In later part of this study, a probabilistic right-turn gap acceptance model is estimated to examine the effects of the simple traffic safety measures on the gap acceptance behavior.

3. DATA COLLECTION

3.1 Target Intersection

This study targets a signalized intersection, named Oike-minami, located in Toyohashi city, Aichi, Japan. At the intersection, the Toyohashi Loop Line (Aichi prefectural road no. 504) with two lanes for each direction and a Toyohashi city road with one lane for each direction are crossed in an X-shaped form (see, Figure 1). The signal control consists of green, yellow, red and right-turn only phase. Due to the unusual form or any other reasons, the intersection records the highest number of traffic accidents in Toyohashi: 43 injury traffic accidents occurred during 2005 ~ 2007, which include vehicle-vehicle collisions, vehicle-bicycle collisions and vehicle-pedestrian collisions. It should be noted that the RTSR collisions involving the right-turn vehicles on the direction-A and the opposite straight-run vehicles on the direction-B, shown in Figure 1 (with left hand-traffic), were 26, i.e. 60% of all accidents occurred there. This study focuses on the driving behavior relating to this type of collisions.

In order to prevent the collisions, the traffic safety measures shown in Table 1 were implemented in December, 2008 (see, Figure 2). The road warning markings and the red color pavements aimed to promote drivers' awareness. Also, The Road Traffic Law Article 34 in Japan states that vehicles must turn right slowly on the inner side of the closest to the center of the intersection. Waiting for right-turn at the position not close to the center of the intersection may leads to not only the delay of following vehicles but also the right-turn longer crossing distance which might increase a collision risk. The drawing of right-turn-wait line and the extension of the median in this implementation aimed to move drivers' right-turn-wait position close to the center of the intersection, which may make the distance of the right-turn shorter.

Table 1 Traffic safety measures implemented in December, 2008

	Direction-A	Direction-B
Number of lanes	2 lanes with a right-turn-only lane	2 lanes with a right-turn-only lane
Safety measures	Red color pavement Road warning markings Drawing of right-turn-wait line Extension of median by soft poles	Red color pavement Road warning markings Drawing of right-turn-wait line

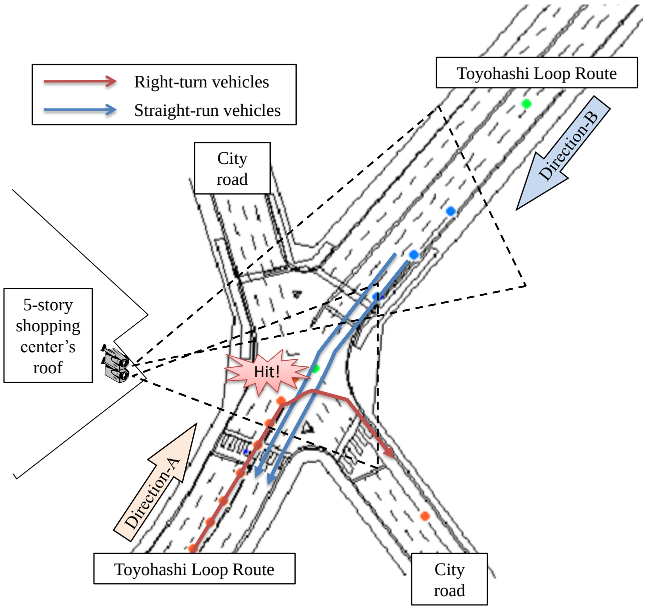

Figure 1 Target intersection, the accident type focused on and video observation

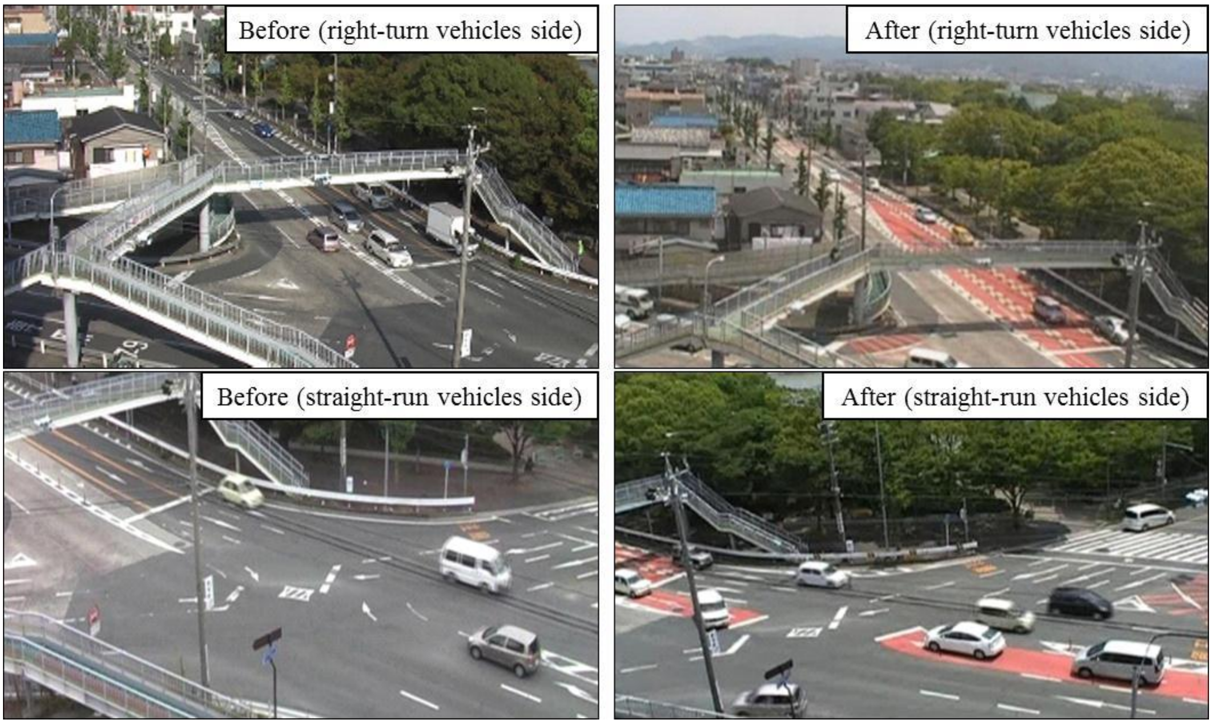

Figure 2 Video images of target intersection before and after the traffic measures

3.2 Video Observation

In order to collect driving behavior data relating to the RTSR accidents before and after implementing the measures, video observations were carried out at 10:00 ~ 12:00 on following three days:

1) Nov. 11st, 2008, as a situation before the implementation;
2) Jan. 13th, 2009, as a situation short period (one month) after the implementation;
3) Jun. 3rd, 2010, as a situation long period (18 months) after the implementation.

By using two video cameras put on the roof parking of the 5-story shopping center, the two areas where the right-turn vehicles' behavior and the opposite straight-run vehicles' behavior could be covered respectively (see, **Figure 1** and **Figure 2**).

3.3 Data Collection from Movie

In this study, the trajectory data of right-turn vehicles and opposite straight-run vehicles were collected by using the following video measurement process. Firstly, the image coordinates (i.e. not real coordinates but coordinates on the image plane) of right-turn vehicles and straight-run vehicles for each 0.5 seconds were collected by mouse click of front-left edges of the vehicles as playing the recorded movies by frames. Next, the collected coordinates were transformed into the real coordinates by using the following two-dimensional projective transformation with pre-estimated parameters:

$$x_i = \frac{A_1X_i + B_1Y_i + C_1}{A_3X_i + B_3Y_i + 1}, \qquad y_i = \frac{A_2X_i + B_2Y_i + C_2}{A_3X_i + B_3Y_i + 1}, \tag{1}$$

where, x_i and y_i are the plane coordinates of point i, X_i and Y_i are the real coordinates of point i, and A_k, B_k and C_k are the parameters.

Based on the collected trajectory data, following indicators were calculated for each right-turn vehicle.

1) *Right-turn-time* (RTT_i) [sec]: the time difference between the time when the front-left wheel of right-turn vehicle i went beyond the right-turn-only lane and the time when the wheel reached the first line of the crosswalk, i.e. TE_i - TS_i in **Figure 3**;
2) *Right-turn-start-position* ($RTSP_i$) [m]: the distance between the center of the intersection and the position of right-turn vehicle i at TS_i (see **Figure 3**);
3) *Spatial right-turn-gap* ($S\text{-}RTG_{ik}$) [m]: the headway distances between oncoming straight vehicle k_i and k_i+1 when the vehicle k_i passed the right-turn vehicle i (see **Figure 4**);
4) *Temporal right-turn-gap* ($T\text{-}RTG_{ik}$) [sec]: the headway time estimated by dividing the $S\text{-}RTG_{ik}$ by the speed of oncoming vehicle k_i+1 when the vehicle k_i passed the right-turn vehicle i. The speeds were calculated using the trajectory data 0.5sec before and after that timing (see **Figure 4**).

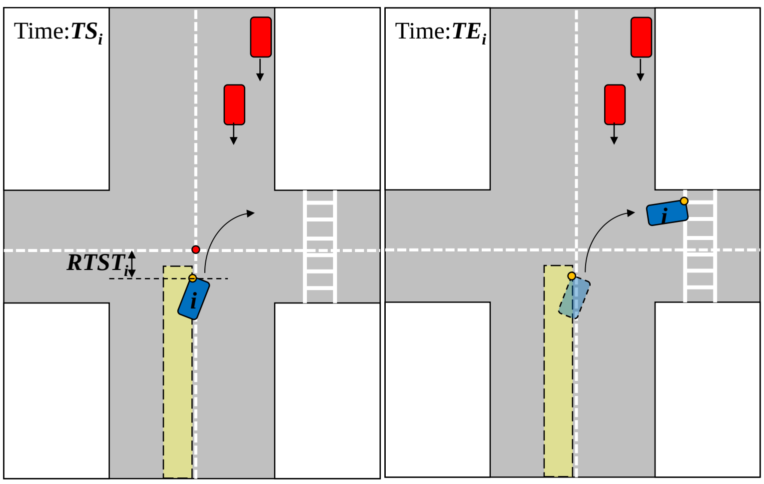

Figure 3 Base concept of RTT_i *and* $RTSP_i$

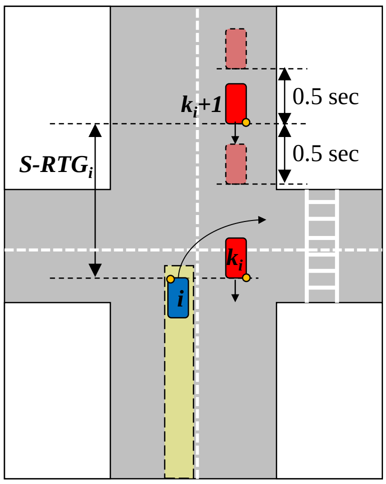

Figure 4 Base concept of $S\text{-}RTG_{ik}$ and $T\text{-}RTG_{ik}$

4. ANALYSIS OF RIGHT-TURN BEHAVIOR

4.1 Right-Turn-Start-Position

Figure 5 shows the distribution of *RTSP* by the video observation timings. It is illustrated that the *RTSP* short period after the implementation became closer to the center of the intersection than those before the implementation. This can be explained as a forced effect due to the extension of the median using the simple poles. It is worth nothing that the *RTSP* long period after the implementation became further closer to the center than those short period after the implementation. This may mean that the effects of these measures increased in the long period. On the other hand, there was no correlation between *RTSP* and *RTT* (r=-0.03), implying that the drivers adjusted their right-turn speeds to the crossing distance. Thus, it is not necessarily the case that this implementation increased the "actual safety".

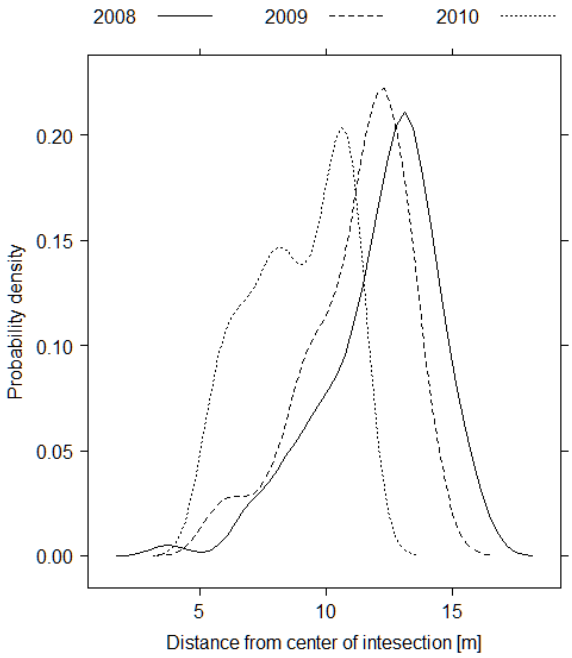

Figure 5 Distribution of *RTSP* by observation timings

4.2 Gap Acceptance Behavior

Although the number of RTSR accidents or the accident rate are likely to depend on the traffic flow or headway distribution of straight-run vehicles opposing to the right-turn vehicles, this study focuses on the rates or probabilities of gap acceptance for various gap sizes in order to analyze the pure effects of the simple traffic safety measures on the right-turn behavior.

Figure 6 illustrates the distribution of *S-RTG* and *T-RTG* faced by the right-turn vehicles and the ratio of the gaps accepted (i.e. hereinafter referred to as *gap acceptance ratio*) which were pooling all observation timings' data. The ward "accepted" means that a right-turn vehicle chose to do right-turn by using the gap faced. Both the gap acceptance ratios for *S-RTG* and *T-RTG* became higher as the gaps increased. It should be noted that the gap acceptance ratio for S-RTG was almost flat in *S-RTG*=60m~80m. This is probably because that although the gap acceptance behavior could be affected by also the speed of the oncoming straight-turn vehicles, the *S-RTG* does not consider the speed. Therefore, *T-RTG* provides more reasonable information and should be used for analyzing change in gap acceptance behavior due to the traffic safety measures.

Figure 7 shows the distribution of *T-RTG* faced by the right-turn vehicles and the gap acceptance ratio by the video observation timings. It is indicated that the ratio of right-turn vehicles accepting shorter gaps (3~4sec) became lower short period after the implementation (2009), especially became zero long period after (2010) while that ratio before the implementation (2008) was roughly 5%. This suggested that the right-turn vehicles came to tend not to accept the shorter gaps because the traffic safety measures promoted the drivers' awareness of safety.

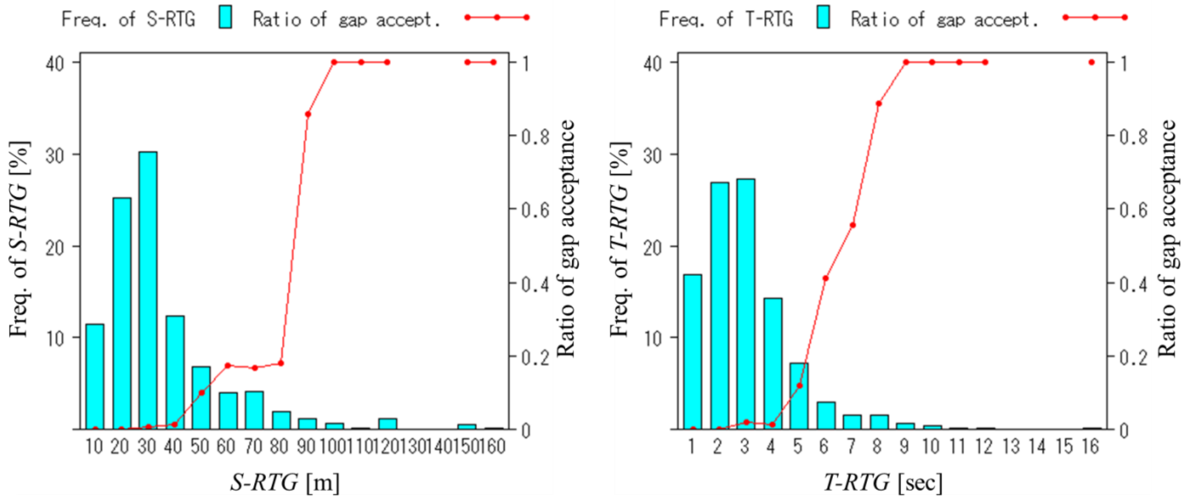

Figure 6 Distributions of *S-RTG* (left) and *T-RTG* (right) occured and gap acceptance ratio

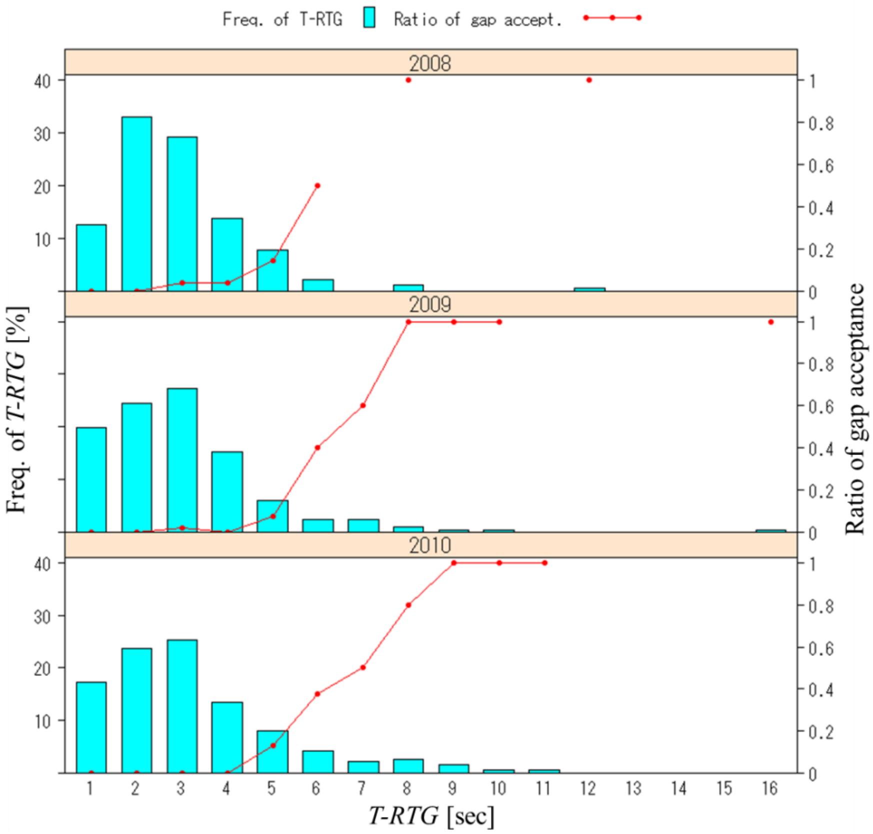

Figure 7 Distribution of *T-RTG* occured and gap acceptance ratio by observation timings

4.3 Gap Acceptance Model

The above analysis about the change in gap acceptance behavior only considers the size of the right-turn gaps. In order to analyze the change in the gap acceptance behavior by considering other condition, modeling approach was introduced. As gap acceptance models, the following logit model was assumed:

$$P_n = \frac{1}{1 + e^{-V_n}}, \tag{2}$$

$$V_n = \alpha_0 + \sum_{k=1} \alpha_k \cdot X_{nk}, \tag{3}$$

where, P_n is the probability of gap acceptance for gap event n, X_{nk} are explanatory variables and α_0, α_k are parameters. *S-RTG* and the speeds of oncoming straight-run or only *T-RTG* were used as the explanatory variables which represent the size of gaps. *RTT* and *RTSP* were also used. And more, since the right-turn vehicles may be more likely to accept gaps as the waiting period for right-turn became longer, the followings were prepared as explanatory variables:

1) *Cumulative passed vehicles* (CPV_n) [veh]: the number of vehicles which the right-turn vehicle had passed since started waiting, for gap event n;
2) *Cumulative waiting time* (CPV_n) [sec]: the time which the right-turn vehicle had waited since started waiting, for gap event n.

As the result of estimating the parameters of the gap acceptance models by the observation timings, **Table 2** shows the most reasonable models. *T-RTG* and *CPV* were selected as explanatory variables while the effects of *TRR* and *RTSP* on the gap acceptance were not found. ρ^2 and hit ratios indicated enough goodness of fit of the gap acceptance models for respective observation timings.

In order to compare the gap acceptance models between the observation timings visually, **Figure 8** shows the curves expressing the probability of gap acceptance against the T-RTG, by using the mean CWT. It is indicated that the curve short period after the implementation (2009) shifted to right by comparison with that before (2008), implying that the right-turn vehicles' judgments of gap acceptance shifted to prudence side or safe side. Also, the curve long after the implementation (2010) was steeper than that short after (2009), indicating that both the ratio of vehicles which *do* turn right with excessively short gaps (less than 4sec) and the ratio of vehicles which *do not* turn right with excessively long gaps (more than 9sec) was decreased. In other words it may be suggested that the efficiency of right-turn was increased long after the implementation of the traffic safety measures which aimed to promote the drivers' awareness of safety.

Table 2 Parameter estimation result of gap acceptance models by observation timings

		Mean	SD	Parameter	p-value	McFadden's ρ^2	Hit ratio
Before (2008) N=182	Intercept	1.00	0.00	-8.30	0.000	0.450	0.945
	T-RTG	2.41	1.45	1.43	0.000		
	CWT	9.23	8.04	0.05	0.459		
Short after (2009) N=217	Intercept	1.00	0.00	-10.0	0.000	0.645	0.935
	T-RTG	2.48	1.84	1.17	0.000		
	CWT	11.0	8.29	0.166	0.008		
Long after (2010) N=185	Intercept	1.00	0.00	-11.4	0.000	0.714	0.897
	T-RTG	2.76	1.94	1.64	0.000		
	CWT	14.2	10.9	0.0897	0.045		

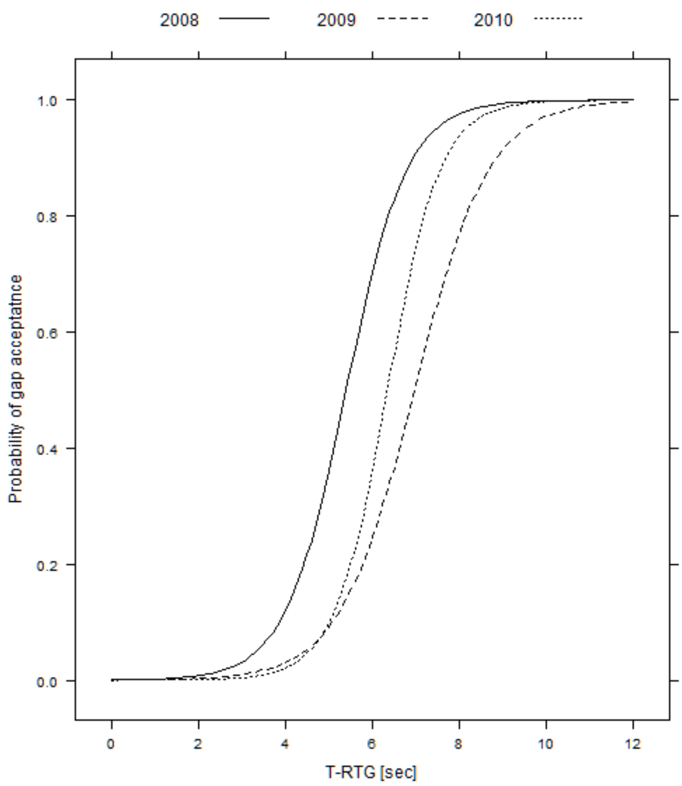

Figure 8 Curves of gap acceptance ratio by the estimated models

5. CONCLUSIONS

Through a before-and-after survey at a signalized intersection where frequent RTSR accidents had occurred and simple traffic safety measures were implemented, this study analyzed the effects of the traffic safety measures on right-turn behavior. In the analysis of the right-turn-start-position, it was indicated that the right-turn vehicles tended to follow the intention of the guide marks (i.e. the drawing of right-turn-wait line and the extension of the median) after the implementation, especially long period after that. However, it is not necessarily the case that this implementation increased the "actual safety".

In the analysis of right-turn gap acceptance behavior, it was illustrated that the ratio of right-turn vehicles accepting shorter gaps became lower after the implementation. Also, by comparing the gap acceptance model using the temporal right-turn-gap and the cumulative waiting time as explanatory variables, the judgment of gap acceptance shifted to safe side. These facts can be interpreted as that the traffic safety measures (i.e. the road warning markings and the red color pavements) promoted the right-turn vehicles' awareness of safety. It is worth noting that the effects of the traffic safety measures in this study grew long period after the implementation (at least 18 month after that) rather than deteriorated. Especially, the right-turn gap acceptance behavior became more efficient.

This study was only a case study and has not found the detailed mechanism of the effects of traffic safety measures above. In addition, this study should consider other factors such as the accelerations of oncoming straight-run vehicles or the change in the traffic flow conditions. Actually, the traffic flow conditions before and after the implementation seemed to be different according to the distribution of right-turn gaps. Intersection geometry is also likely to be an important factor affecting the gap acceptance behavior. For solving these issues, further studies are needed.

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