ANALYSIS AND MODELLING OF DRIVER PREPARATORY BEHAVIOUR BEFORE TURNING AT INTERSECTIONS

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ABSTRACT: This study focuses on an analysis and modelling of the naturalistic driving behaviour before making a right turn at an intersection. We developed instrumented vehicles and conducted long-term experiments on a public road to measure driver behaviour, vehicle state, and headway and rear distances. The relationships between the onset locations of covering the brake pedal and activating the turn signal and the traffic conditions of driving with or without lead and/or following vehicles were analyzed based on the data measured in the real road environment. The results suggest that the existence of the front and rear vehicles and the vehicle velocity influence the onset location of covering the brake pedal. Structural equation modelling was applied to estimate these relationships quantitatively. The results imply that the model with two latent variables, free-driving condition level and location of transition to preparatory behaviour, can represent the hypotheses obtained from the naturalistic behaviour analysis. Finally, we investigated the driver preparations before making turns at other intersections with various road structures and discussed the differences of the influence of the traffic conditions between the road environments.

1 Introduction

The popularization of in-vehicle navigation and telecommunication systems is progressing rapidly all over the world as one of key components for realizing ITS. Drivers use route guidance information via the in-vehicle navigation systems while driving from the origin to the destination. The route guidance instruction helps drivers to choose and maintain the correct routes with lower mental workload. In this study, we focused on the presentation timing of the voice instruction just prior to making the turn. This information can trigger a change in driving behaviour from straight mode to preparation mode while approaching a target intersection. The presentation timing is usually constant in any road traffic conditions. However, the constant timing can lead to a reduction in the driver acceptance of the provided information, because there may be some variations in the driving operations due to the influence by the road traffic environment [1]. It is essential to develop a human-centred design, i.e. to develop a presentation timing adapted to the typical driver's preparatory behaviour before making a turn at an intersection based on the investigation on the naturalistic driving behaviour under actual road traffic environments.

We conducted long-term experiments using instrumented vehicles on a public road in order to measure the natural driving behaviour before making a right turn at a specific intersection. This experiment was carried out in left-hand

driving, i.e. under Japanese traffic contexts. We focused on leading and following vehicles as the traffic conditions in the vicinity of the target intersection. In this study, the leading vehicle is defined as a forward vehicle that travels straight toward the target intersection. We did not analyze the traffic situations in which the forward vehicle turned to the right, as did the driver's own vehicle, because the stopping locations for waiting for the right turn when there are leading vehicles stopping at the target intersection are different from those without the leading vehicles. The following vehicle is defined as a vehicle that follows the driver's vehicle in the same traffic lane, regardless of whether or not the following vehicle turns to the right at the turning point.

1.1 Aims of this study

(a) Analyze naturalistic driving behaviour before making a right turn at a specific intersection and investigate the influence of the traffic conditions in the vicinity of the target intersection on the onset location of the driver's preparatory behaviour.

(b) Construct a driver model for describing the relationships between the traffic conditions and the driver behaviour.

(c) Investigate the driver's preparatory behaviour before making turns at other intersections with various road structures in order to clarify the road conditions where the driver's behaviour is influenced by the existence of the leading and following vehicles.

2 Experiments

2.1 Participants

Four non-professional drivers (three males and one female) participated in the long-term experiments. The average age of the participants was 34.8 years (age range: 22 - 52 years). The average driving experience was 16.3 years (experience range: 3 - 33 years). All participants drove a passenger vehicle almost every day in their daily lives.

2.2 Experimental vehicle

Figure 1 presents an instrumented vehicle to measure driver behaviour used in this experiment. Various sensors and a recorder system detected the vehicle driving state, including vehicle velocity, vehicle acceleration, and geographical position, and measured driver's behaviour, including steering, accelerating, and braking operations. The relative distance and relative speed of the lead and following vehicles were measured with two laser radar units attached to the front and rear bumpers. The driver's foot position (covering the accelerator pedal or brake pedal without pressing) was detected by laser sensors fitted above the pedal surfaces. The turn signal activation was detected by adding encoders to the lever. The data was recorded on a laptop computer and mobile hard disks via a driving recorder system. This recorder system was fixed inside the trunk of the instrumented vehicle to encourage naturalistic driving behaviour of the participants.

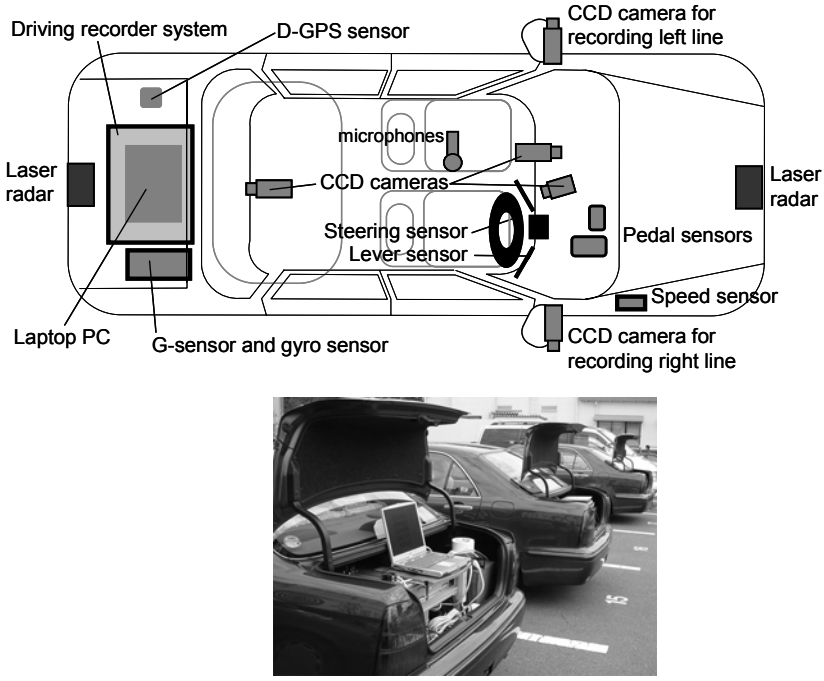


Fig.1. Overview of the instrumented vehicle

2.3 Target intersection

We carried out repeated experiments on a public road in Tsukuba. The selected driving route was a 30-minute trip (total mileage: about 15 km) that included several left and right turns. Figure 2 presents a diagram and images of the analyzed intersection on the experiment route. The intersection has a designated lane for making a right turn. There is a long straight road about 2 km as far as the target intersection, which has two traffic lanes.

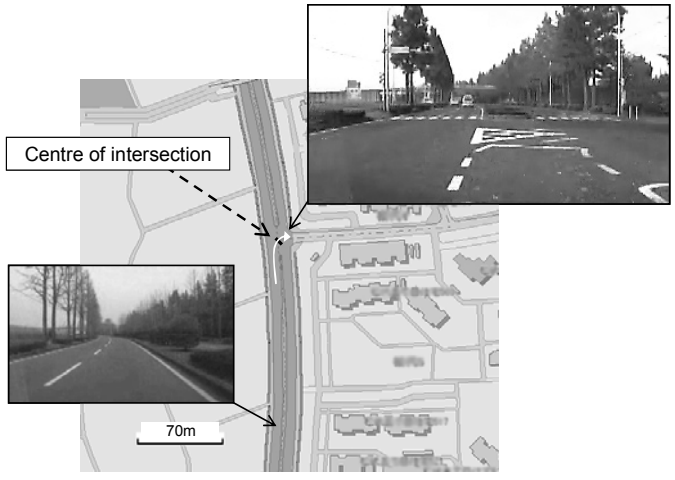


Fig.2. Overview of the target intersection

2.4 Variables

Driver's preparatory behaviour before making the turn corresponds to activating the turn signal and decelerating. We focused on the foot movement to cover the brake pedal as the decelerating operations.

The behavioural events were quantified by using the remaining distance to the centre of the target intersection (the stop line for turning to the right) at the onset of each preparatory manoeuvre. In an analysis of the driver preparatory behaviour, we investigated the onset location of each operation by classifying the traffic conditions while approaching the target intersection, i.e. driving with both leading and following vehicles, driving with a leading vehicle and without a following vehicle, driving without a leading vehicle and with a following vehicle, and driving without either a leading or following vehicle, in order to clarify general influence of the traffic conditions on the preparatory behaviour. The driving with a leading or following vehicle was defined as the existence of a vehicle running in front of or to rear of the driver's own vehicle before the driver entered the designated right-turn lane. In a construction of the driver model, we used the vehicle velocity when the brake pedal was covered by the driver's right foot, the remaining distances at the onset of each preparatory behaviour, and the relative distances to the leading and following vehicles before the driver entered the designated right-turn lane, in order to evaluate in detail the impacts of the traffic situations on the preparatory manoeuvres.

2.5 Experimental procedure

We developed the four instrumented vehicles, and four participants started driving on the identical route at 10-min intervals to measure each participant's driving behaviour under similar traffic conditions. The recorded trip was made once a day on weekdays and the total was 40 trips (over a period of about eight weeks). Practice drives were made before the measurement trials so that the participants could drive from the origin to the destination without using a map. The participants rode alone in the instrumented vehicle during the experiment trials. They were instructed to drive in their typical manner.

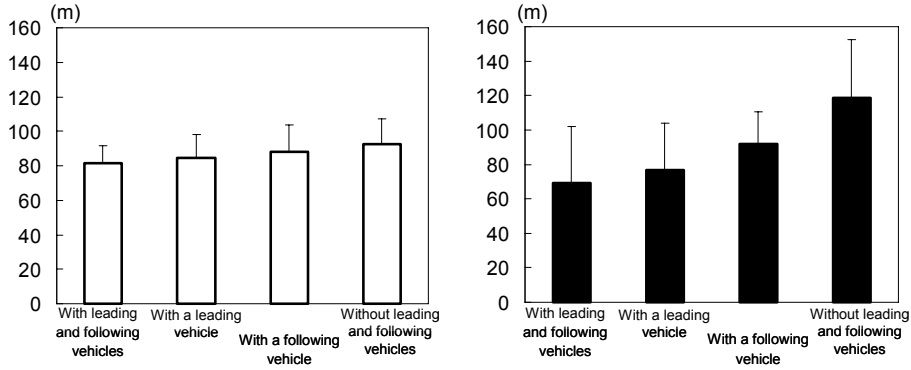
3 Analysis of driver preparatory behaviour

The average remaining distance to the centre of the target intersection when each behavioural event occurred was calculated in the categorized traffic conditions. Figure 3 presents the results of the relationships between the onset location of the driver preparatory behaviour and the traffic conditions.

The remaining distances to the centre of the target intersection when covering the brake pedal without either a leading or following vehicle were the longest among the four traffic conditions. The closest onset locations of the right foot movement were found when driving with both leading and following vehicles. The existence and number of other vehicles around the driver's vehicle may influence the onset location of driver's decelerating manoeuvre.

The remaining distances when activating the turn signal with leading and following vehicles were shorter than those during trials without leading and

following vehicles. However, the decreasing tendencies were not remarkable compared to the results of covering the brake pedal. The onset location of the turn signal activation ranged from 80m to 95m and was independent of the existence of other vehicles in front of or to rear of the driver's vehicle.



(a) Cover a brake pedal (b) Activate a turn signal

Fig.3. Average onset location of each behavioural operation in the four traffic conditions

It is hypothesized that the drivers drive at a lower speed when they follow a forward vehicle. Figure 4 confirms this hypothesis. The driving speeds while driving with leading and following vehicles and with a lead vehicle were lower than those of the driving conditions without a leading vehicle. The participants drove the fastest when the leading and following vehicles did not drive in front of and to rear of the participants' vehicles.

In the comparison analyses of the driver's preparatory behaviour in a restricted vehicle velocity from 16m/sec to 17.5m/sec, it was suggested that the locations at the onset of covering the brake pedal were closer to the centre of the intersection when driving with leading and following vehicles, compared to driving without a leading vehicle.

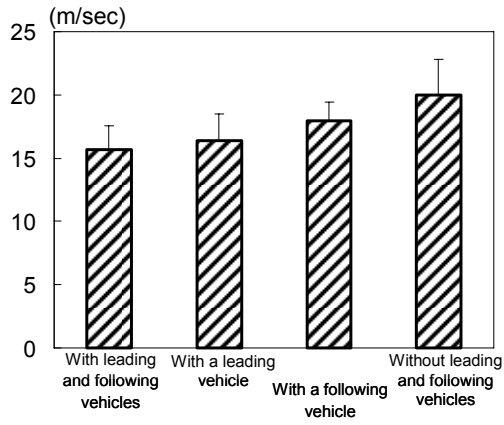


Fig.4. Average driving speed when covering the brake pedal in the four traffic conditions

4 Modelling of driver preparatory behaviour using structural equation model

4.1 Method and result

The behavioural analysis suggests that the existences of leading and/or following vehicle correlate with the vehicle velocity while approaching the target intersection. The experiment results reveal a linear relation between the onset location of driver's preparatory behaviour and the traffic conditions. We evaluate these relationships quantitatively by using the structural equation model with the following five variables: the vehicle velocity, the relative distance to the leading vehicle, the relative distance to the following vehicle, the remaining distance to the centre of the target intersection when covering the brake pedal, and the remaining distance to the centre of the target intersection when activating the turn signal. When there are no leading and following vehicles while approaching the target intersection, the relative distances to the forward and rear vehicles were compensated with the driving speed based on a regression equation between the driving speed and the headway or rear distance under conditions of driving with leading or following vehicles.

Figure 5 presents a path diagram of the proposed structural equation model after several trials of model construction and estimation, and the results of model fit indices. We introduced two latent variables, free-driving condition level describing relative distances to leading and following vehicles and location of transition to preparatory behaviour describing onset locations when covering the brake pedal and activating the turn signal.

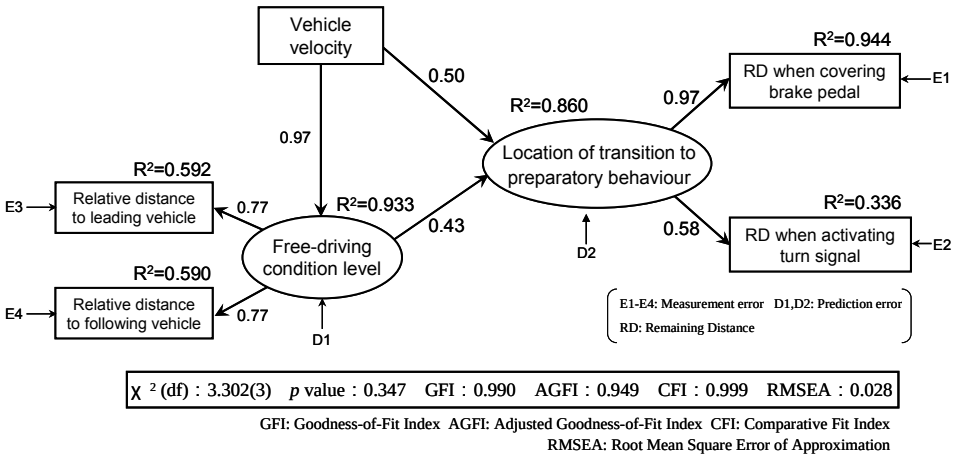


Fig.5. Path diagram of the constructed structural equation model

The chi-square value is non-significant, indicating an acceptable model-to-data fit. In addition, the results of the model fit indices demonstrate that the proposed structural equation model fits the observed data well. The path coefficients between the vehicle velocity and the location of transition to preparatory behaviour and between the free-driving condition level and the location of transition are almost equal, suggesting that the influence on the onset locations of the preparatory behaviour is almost equal between from the vehicle velocity

and from the relative distances to the leading and following vehicles. The factor loadings from the location of transition to preparatory behaviour to each preparatory manoeuvre present the difference in the impacts of the driving speed and the traffic conditions on each onset location, i.e. the two factors have large effect on the onset location of covering the brake pedal and have less effect on the location at the onset of activating the turn signal, corresponding to the analysis results of the driver preparatory behaviour.

4.2 Implication for route guidance presentation

The constructed structural equation model suggests that the driving speed and the relative distances to lead and following vehicles should be taken into account when determining the presentation criteria of the route guidance instruction. This is because the driver's onset location where they begin to decelerate before making the turn differs according to the vehicle velocity and the traffic conditions while approaching the target intersection. For example, the presentation timing can be closer to the target intersection when drivers drive slowly or they follow a lead vehicle.

In addition, the proposed structural equation model may contribute to predicting the onset locations of the driver's foot movement to cover the brake pedal and turn signal activation, based on the vehicle velocity and the relative distances to leading and following vehicles when the route guidance information is provided for drivers. We confirm higher prediction accuracy of the proposed structural model, compared to the prediction by a single regression model of vehicle velocity, by evaluating the differences between the predicted values and the observed values at the onset of each behavioural event which were not used for the model construction. The in-vehicle system linked with the speed pulse sensor and laser radar units can predict the driver's onset location of preparation for a right turn by using the path coefficients of the constructed structural model. If driver does not begin to prepare to make a right turn after reaching the predicted onset location, the system can access the driver's navigational error, i.e. the driver did not accurately identify the turning point, or did not notice the information provision, and then restate the route guidance or issue a warning.

5 Application to other intersections on other manoeuvres and with various road structures

We focus on only one specific intersection with two traffic lanes and a designated right-turn lane. We analyse the driver's preparatory behaviour while approaching the other intersections with various road structures and on the other manoeuvres involved with a left turn, and investigate the influence of the existence of the leading and following vehicles on the onset location of the driver's decelerating manoeuvre.

Figure 6 presents an overview of the analyzed intersections on the same experimental route as the target intersection in Fig. 2. Intersection 2 has two traffic lanes, and the other intersections have one traffic lane. The participants

made a left turn at Intersection 2 and Intersection 6. They approached Intersection 4 and Intersection 6 after driving along curves.

Figure 7 presents the results of the onset locations of covering the brake pedal in the four categorized traffic conditions at each intersection. At Intersection 1, Intersection 2, and Intersection 5, the remaining distances to the centre of the intersections while driving with leading and following vehicles were shorter compared to the drives without either a forward or rear vehicle, indicating the similar tendencies to the analysis at the specific intersection with a designated right-turn lane.

At Intersection 4 and Intersection 6, the onset locations of the root movement to cover the brake pedal while driving with the leading and following vehicles were the longest among the four traffic conditions. The drivers tended to begin to prepare to make a turn at an earlier point while they approach the intersection after a curve in a car-following condition compared to in a free-driving condition.

At Intersection 3, the onset location of covering the brake pedal is closer to the centre of the intersection while driving with only a leading vehicle or without leading and following vehicles, compared to driving with a following vehicle. A road construction was conducted around Intersection 3, and the participants tended to begin to decelerate earlier while approaching the intersection with a following vehicle, due to avoidance of the rear-end collision caused by the following driver who is distracted from noticing the intersection.

The results of the additional analyses suggest that the same relationships between the driver's preparatory behaviour and the traffic conditions as the specific intersection with a designated right-turn lane are found on the left-turn manoeuvre and the intersection with one traffic lane where there is no designated lane for making a turn. However, the relationships are different on the intersection with a road construction and the intersection after a curve. It is important to take into consideration the traffic conditions in a different manner when determining the route guidance presentation criteria at the intersections with a curve or a road construction.

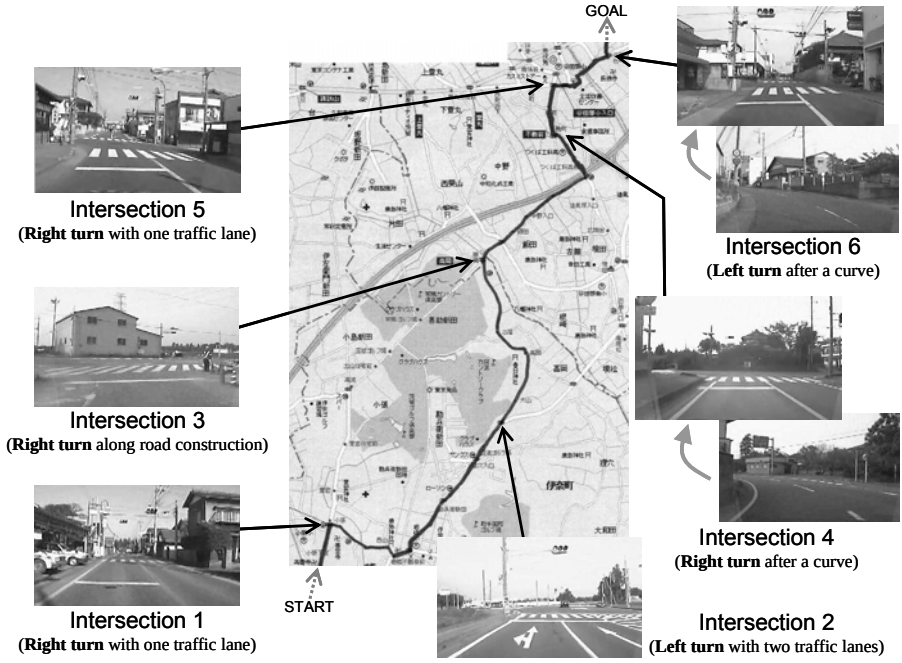
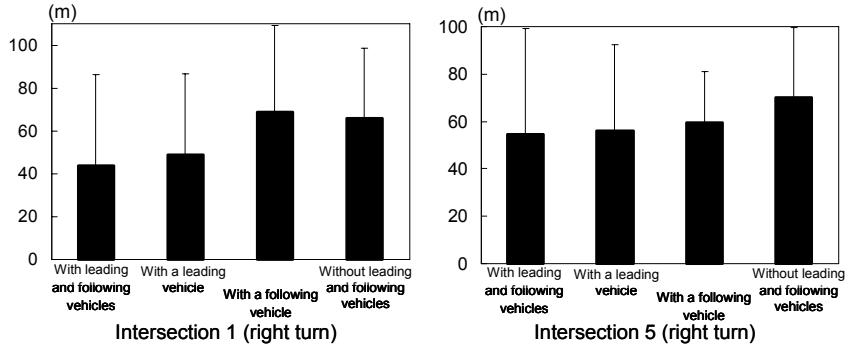


Fig.6. Map of the experimental route and analyzed intersections

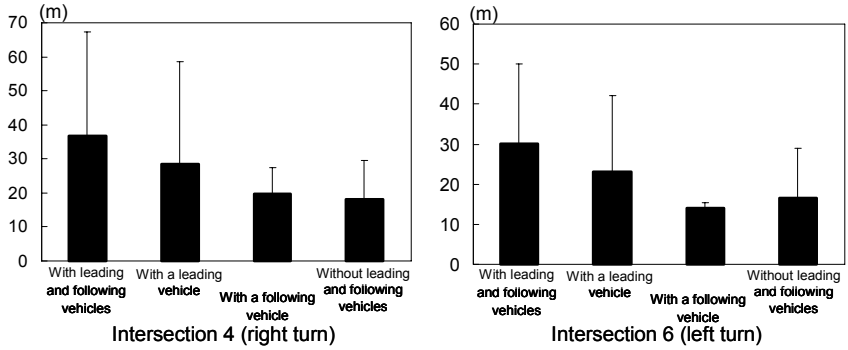
6 Conclusion

We developed instrumented vehicles and conducted experiments on a public road to measure driver's preparatory behaviour while approaching intersections, vehicle velocity, and traffic conditions around the driver's vehicle. The relationships between the onset locations of covering the brake pedal and activating the turn signal and the existence of the forward and following vehicles were analyzed based on the data measured at a specific intersection with a designated right-turn lane. The results suggest that the existence of the front and rear vehicles and the vehicle velocity influence the onset location of covering the brake pedal. Structural equation modelling was applied to estimate these relationships quantitatively. The results imply that the model with two latent variables can represent well the hypotheses obtained from the naturalistic behaviour analysis.

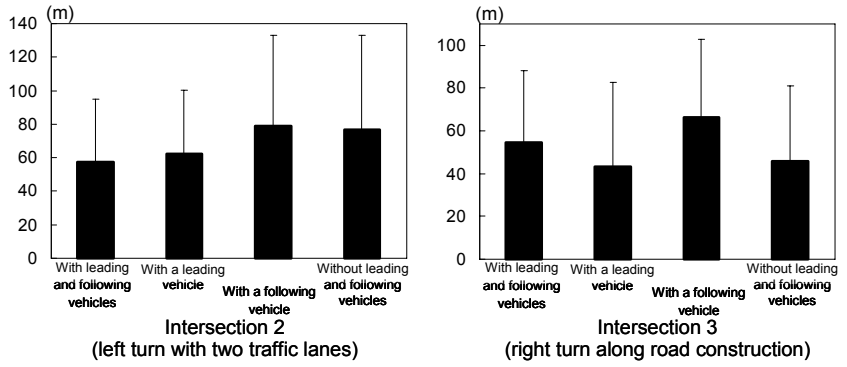
Finally, we investigated the driver preparations before making turns at other intersections on the other manoeuvre and with various road structures. The additional investigation results indicate that the traffic conditions around the driver's vehicle and the driving speed have an influence on the onset location of the driver's decelerating operation before making a left turn or while driving on one traffic lane, and the influence is the same as the specific intersection with the designated lane. However, the influence differs at the intersections with a road construction and the intersection after a curve. Further studies with various categories of drivers will be conducted to validate the findings obtained from this analysis.



(a) Standard Intersections with one traffic lane



(b) Intersections after a curve



(c) Other Intersections

Fig.7. Average onset locations of covering the brake pedal on the analyzed intersections

7 References

[1] Yoshioka, M., Akamatsu, M. Matsuoka, K. and Sato, T. 'Aim of behavior-based human environment creation technology'. Proc. of the XVth Triennial Congress of the International Ergonomics Association, 2003, CD-ROM