International Advance Journal of Engineering Research (IAJER)
Volume 2, Issue 6 (June- 2019), PP 18-28
ISSN: 2360-819X
www.iajer.com

Research Paper **Open Access**

Method to Set the Control Start Timing of Pedestrian AEB System for Preventing Excessive Dependence

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ABSTRACT : *The purpose of this study is to explain the methodology of setting an optimum value for the braking control timing of AEB system designed to prevent collision with pedestrians. For marketing the system, control intervention should be activated as soon as possible to minimize the damage caused by collision accidents and ensure that the drivers have a high trust in the system, but if the control start timing is too early and interferes with the braking operation of the drivers, then such a system may lead to excessive dependence because of over-trust. In the experiments, start timing of applying the brake by the drivers was analyzed for 15 subjects using a driving simulator. Based on the cumulative frequency analysis of the start timing of applying the brake by the drivers, experiments were conducted with the system performing braking control at 4 timings, namely 1st percentile, 5th percentile, 50th percentile, and the physical avoidance limit. An experimental study was performed in the experiments to examine whether operation interference takes place between the driver and system. In this experiment, the relation between the operation interference and the degree of dependence on the system were also examined.*

Keywords -*Safety, Driving Support, Overconfidence, Accident avoidance, AEB, Control Timing, Over-Trust*

I. INTRODUCTION

Guidelines must be proposed for the design of practical application of the driver assistance system that supports the operations performed by the driver while driving to maintain the overall safety as a human and automotive system even if the driver makes mistakes in operations, and the system must function better compared to the situation in which the system is not put to practical use. For example, unless a system is developed that can control the over dependence induced by the over-trust of the driver on the system capability, a negative effect that is caused by the over dependence may become noticeable over the positive effect expected in practical application of the driving assistance system. For example, while driving on a highway with a vehicle equipped with Adaptive Cruise Control (ACC) and Autonomous Emergency Braking (AEB), there are cases where the driver neglected to check the situation on the road ahead and collided with the vehicle that had stopped in front due to a traffic congestion [1]. In this way, over dependence induced by over-trust in the assistance systems may bring down the overall safety as a human and automotive system compared with situations where such assistance systems have not been put to practical use.

As reported by Lee et al. [2], over-trust is the result of the judgment “All conditions are satisfied” even when at least one of the following four dimensions is not satisfied.

Fundamental: Consistent with the fundamental assumption of natural and social order.
Performance: Consistently stable and desirable performance or behavior is expected.
Process: Understanding of the process, algorithms, and rules that govern behavior.
Purpose: Understanding underlying motives or intents.

Let us consider a driving assistance device that is used to assist in preventing accidents. Since the collision avoidance assistance brake operates only when the risk of collision is extremely high, the “Opportunity for observation [3]” of how the brake functions is limited during normal driving. If the system operates frequently even when the risk of collision is small, the driver may form a wrong mental model concerning performance of the above four dimensions. In other words, this over-trust in the driving assistance function may manifest as an excessive dependence and obstruct the behavior of braking operation that must be performed by the drivers. What are the measures necessary to control over-trust? In a previous study by one of the authors Suzuki et al. [4], an example of a collision prevention assistance system with the vehicle in front was cited, and the study suggested that for preventing over-trust braking control by the system must not interfere with the braking operation of the driver. Specifically, this suggests that the key point is setting the start timing of braking by the system after the start timing of brake application by the driver and earlier than the timing of physical avoidance limit. The optimum start timing for system control has not been discussed sufficiently in the previous study. For marketing the system, control intervention should be activated as soon as possible to minimize the damage caused by collision accidents and ensure that the drivers have a high trust in the system, but if the control start timing is too early and interferes with the braking operation of the drivers, then such a system may lead to excessive dependence because of over-trust.

Based on the above background, the purpose of this paper is to explain the methodology of setting an optimum value for the braking control timing using the example of AEB system designed to prevent collision with pedestrians. First, the macro data collected by the Institute for Traffic Accident Research and Data Analysis (ITARDA) on the number of accident fatalities for several types of roads was used to identify the traffic environment with high incidence of traffic accidents between pedestrians and vehicles. The result indicated that the traffic accidents while driving on a straight road and when turning right at intersections is high [5]. These two scenarios were set as the driving environment in a driving simulator and experimental subjects were used to analyze braking behavior of the drivers. Based on the results, the methodology to set an optimum value for the start timing of braking control that can prevent excessive dependence of drivers because of over-trust was examined. Specific examples of implementation items are given below.

#01 Analysis of Start Timing of Applying the Brake by the Drivers

Start timing of applying the brake by the drivers was analyzed for 15 subjects using a driving simulator. For straight road, the start timing of applying the brake by the drivers was analyzed in terms of the Time to Collision [s] (TTC, relative distance [m]/relative speed [m/s]) between the vehicle and pedestrian in the longitudinal direction, and lateral distance between the pedestrian and vehicle edge [m] as the evaluation indices. For turning right at an intersection, the start timing of applying the brake by the driver was analyzed using TTC and relative distance between the vehicle and pedestrian as evaluation indices.

#02 Analysis of Operational Interference Between Driver and System, and Relationship Between Dependence and Trust

Based on the cumulative frequency analysis of the start timing of applying the brake by the drivers in the above two traffic scenarios, experiments were conducted with the system performing braking control at 4 timings, namely 1st percentile, 5th percentile, 50th percentile of brake operation timing of 15 subjects, and the physical avoidance limit. An experimental study was performed in the experiments to examine whether operation interference takes place between the driver and system. In this experiment, the degree of dependence on the system and degree of trust were examined by subjective evaluation with a questionnaire to evaluate the braking intervention timing by AEB system.

II. PREVIOUS STUDIES ON BEHAVIOR TO AVOID COLLISION WITH PEDESTRIANS

Some of the examples of previous studies on collision accidents between pedestrians crossing road and automobiles are given below. For example, a study by Hiramatsu et al. [6] has reported that in cases where a pedestrian starts crossing from the left side as viewed by the driver, pedestrians rushing out in front of the car is the main cause for collision accidents, while in cases where a pedestrian starts crossing from the right side, carelessness of the driver is the main cause for collisions. There are reports of simulation of collision avoidance behavior[7]-[9] of drivers with pedestrians who rush out from behind parked vehicles. Futagami et al. [10] and Ishibashi et al. [11] are conducting studies to identify the main causes of collision accidents when turning right at an intersection. These studies have concluded that the psychological burden on driversincreases as they plan to turn right while steering, due to which the resources allotted for attention on pedestrians decreases, leading to collision accidents with the pedestrians.

Although previous studies have been conducted as described above, there are few analysis examples that have considered the start timing of brake application by drivers when avoiding collisions with pedestrians using evaluation indices, for example, TTC and buffer distance between the vehicle and pedestrian. The authors believe to investigate braking behaviour of drivers and optimizing the start timing of braking control by the system is important for controlling the interference between the braking operation by the driver and system. In this paper, we investigated the start timing of brake application by drivers when avoiding collisions with pedestrians as given in Section 3 below. We will examine the start timing for braking control by the system that can prevent over-trust of the user on the system based on the investigation results.

III. ANALYSIS OF COLLISION AVOIDANCE TIMING WITH PEDESTRIANS

3.1. Straight Road

3.1.1. Traffic Scenario

A straight road as shown in Fig. 1 was set as the traffic environment for the driving simulator. In this driving environment, the start timing of applying the brake when avoiding collisions with pedestrians with braking operations was analyzed. The running speed was set to 40 [km/h] in this experiment based on the micro data published by ITARDA [5]. The survey results [12] on the walking speed of 707 people on urban street sidewalks show that the average walking speed of pedestrians is 1.38 [m/s]. The pedestrian speed was set to 5 [km/h] in this experiment. Using this condition, a pedestrian was set to start walking in the direction of the road at five different levels of timing shown in Table 1. For instance, when a pedestrian was set to start at 3.0 seconds in terms of TTC, the collision position between the vehicle and pedestrian is on the left side of the vehicle.

To restrict the subjects from becoming oversensitive to pedestrians dashing into the road, dummy events were set up in which there were no actual collisions. Events where pedestrians start walking and stop on the sidewalk at the same timing of dashing into the road and where pedestrians change the direction within the sidewalk were set up as dummy events.

The subjects were assigned the Uchida Kraepelin Task [13] to prevent excessive attention to pedestrians and simulate the close call situations with increased risk of collision. In this task, one-digit numbers are drawn on the front screen of the driving simulator at intervals of 3 seconds, and the subjects must answer the first digit of the result obtained by adding the next number to the displayed number.

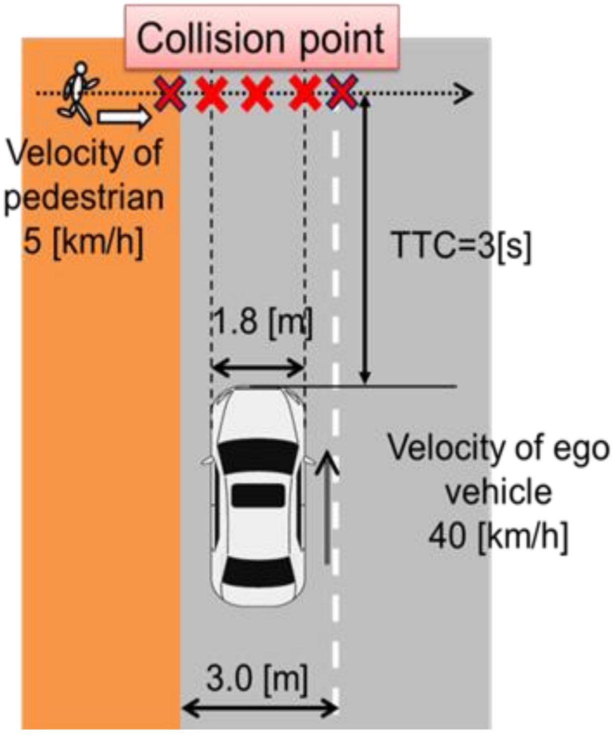


Fig. 1 Traffic scenario (straight road)

Table 1Estimated positions of impact and timings of pedestrians running onto the road in the experiment.

Event conditions	Estimated position of impact	Timing of pedestrian running out in terms of TTC (=D[m]/V[m/s])
Approaching	0.90 m to the left from the left edge of the vehicle	TTC=2.35 s
Left edge	Left side of vehicle	TTC=3.00 s
Centre	Centre of vehicle	TTC=3.65 s
Right edge	Right side of vehicle	TTC=4.30 s
Passing	0.90 m to the right from the right edge of the vehicle	TTC=4.95 s

3.1.2. Subjects

The subjects were 15 young males (mean age 23.0 ± 1.4 years). One week before starting the experiments, the person conducting the experiments explained the experiment contents to the subjects. Consent of the subjects was obtained with the informed consent form just before starting the experiments.

3.1.3 Start Timing of Brake Application

The start timing of brake application for 15 subjects is shown inFig.2. As shown in the figure, the limit value (latest timing) for the start timing of applying the brake by the 15 subjects can be shown using TTC in the longitudinal direction, and lateral distance between the vehicle edge and pedestrian. We will discuss a method to set the control start timing of AEB system based on this result for the straight road in Section 4 below.

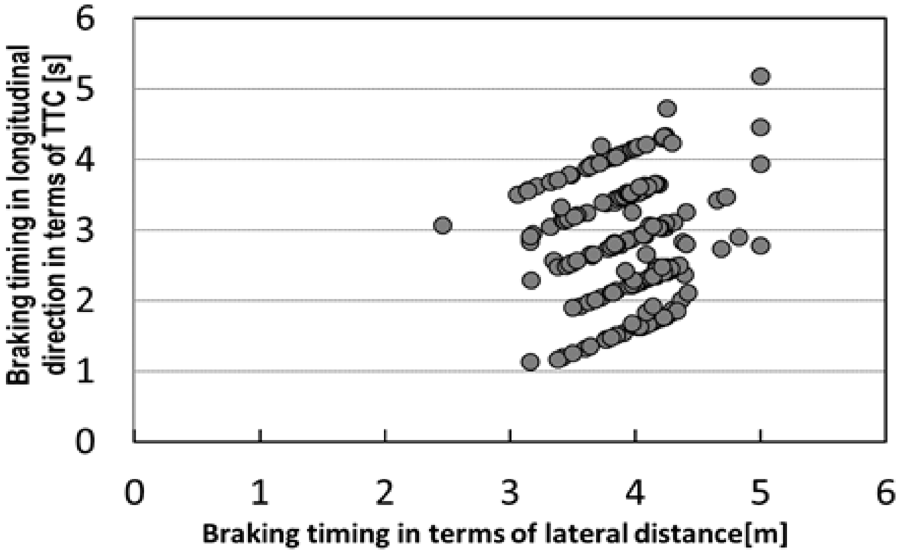


Fig.2 Start timing of brake application (straight road)

3.2. Right Turn at Intersection

3.2.1. Traffic Scenario

An intersection as shown in Fig.3 was set as the traffic environment for the driving simulator. In this driving environment, the start timing of applying the brake by the drivers when avoiding collisions with pedestrians while turning right at the intersections was analyzed. The running speed was set to 20 [km/h] in this experiment based on the micro data published by ITARDA [5]. The pedestrian speed was set to 5 [km/h] as in the case of straight road. In the above-mentioned experiment on a single straight road, five levels of timings when a pedestrian jumpsout to the roadway are set. At the pre-study of investigation, the experimental results showed that the analysis of the brake operation for the driver to avoid collision with the pedestrian can be grasped only by the crash condition at the left end of the vehicle, and all driver mentioned that it is easy to understand and estimate collision timing in this condition. Therefore, in the experiment at the intersection right turn below, only the conditions under which the pedestrian collides at the left edge of the vehicle were set.

Using this condition, a pedestrian was set to start walking at the timing when the TTC between the vehicle and pedestrian was 3.0 seconds such that the collision position between the vehicle and pedestrian is on the left edge of the vehicle.To restrict the subjects from becoming oversensitive to pedestrians dashing into the road, dummy events were set up in the same way as the straight road.The experiments were conducted in the same way as the straight road, and subjects were assigned the Uchida Kraepelin Task to simulate close call situations.

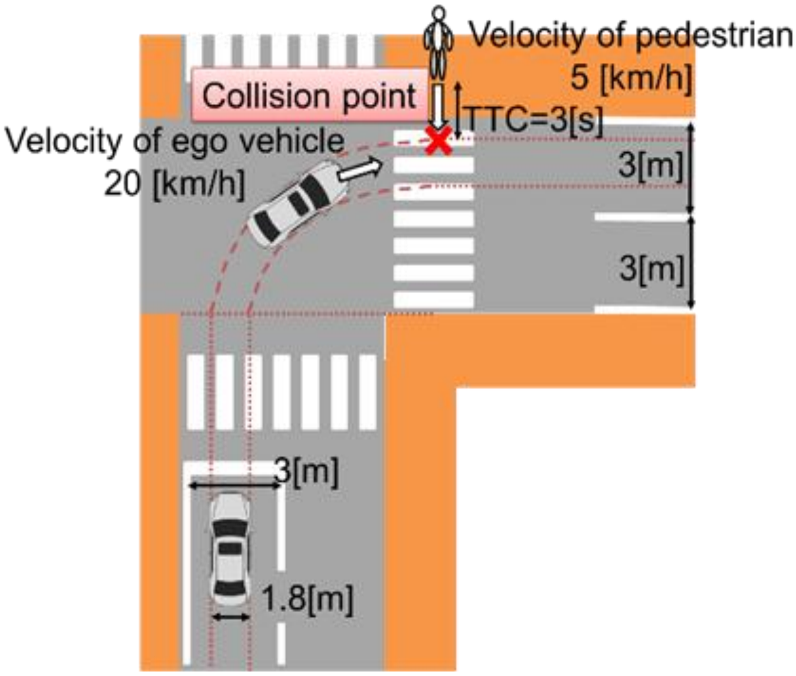


Fig. 3 Intersection scenario (Right turning at intersection)

3.2.2. Subjects

The subjects were 15 young males (mean age 22.9 ± 1.4 years). The contents of the experiment were explained to the subjects in the same way as the experiments conducted on a straight road and consent was obtained with the informed consent form just before starting the experiments. To restrict the subjects from paying excessive attention to pedestrians dashing into the road, the experiments were conducted with subjects who had not participated in experiments for the straight road in a previous study.

3.2.3. Start Timing of Applying the Brake

The start timing of brake application for 15 subjects is shown in Fig.4. The limit value can be explained using TTC in the longitudinal direction in the same way as the straight road shown in Fig.2. While traveling to the right at the intersection, the vehicle travels while turning at the intersection. For this reason, limit value using the lateral distance between the vehicle edge and pedestrian cannot be explained in the same way as the straight road. Therefore, the start timing of applying the brake was explained using the relative distance between the pedestrian and vehicle. We will discuss a method to set the control start timing of AEB system based on this result for the right turning at intersection in Section 4 below.

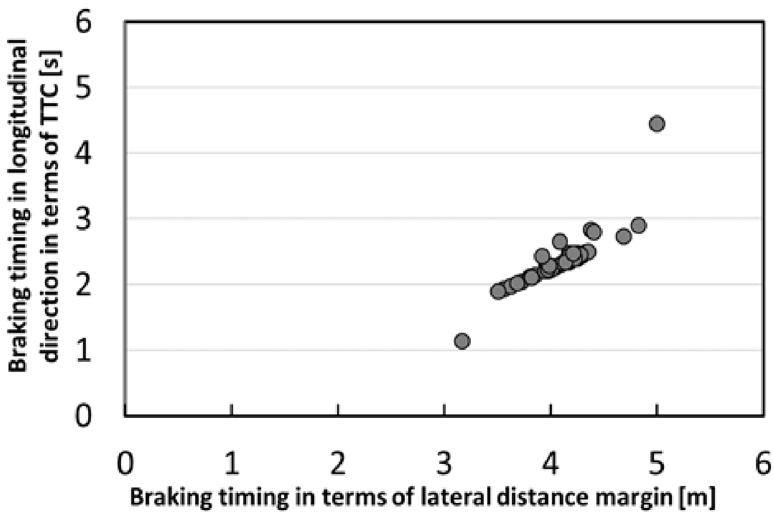


Fig.4 Start timing of applying brake (Right turning at intersection)

IV. START TIMING OF BRAKING CONTROL FOR CONTROLLING OPERATION INTERFERENCE

4.1. Driver Classification Based on DSQ

In this section, a method to set the start timing of braking control by the system to later than the start timing of applying the brake by the driver and earlier than the timing of physical crash avoidance limit is discussed. In other words, the lower limit value (e.g.value with the shortest TTC) of start timing of applying the brake by the driver was analyzed. In this analysis the start timing of applying the brake by the drivers was assumed to differ due to differences in driving styles. Using the results of the Driving Style Questionnaire (DSQ) [14], characteristics of the start timing of applying the brake for each driver group was studied by classifying driver groups using cluster analysis. Ward method that has a high classification sensitivity was used for cluster analysis.

The characteristics obtained by cluster analysis for each driver group is shown in Fig.5 and Fig.6. For example, drivers classified in Group #A scored high evaluation points for "Confidence in driving skills". We will discuss these driver characteristics and braking operation timing at section 4.2 below.

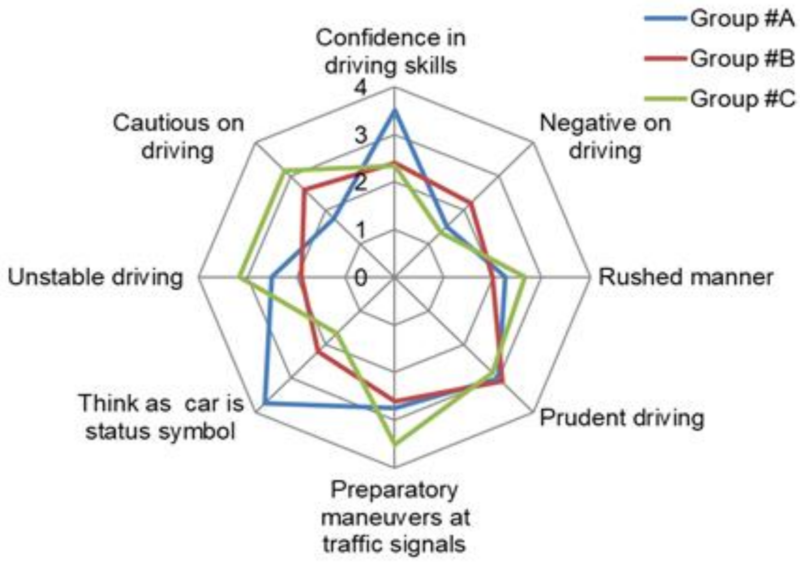


Fig. 5 Straight driving road condition Driving characteristics of each group (n=15 subjects for straight road)

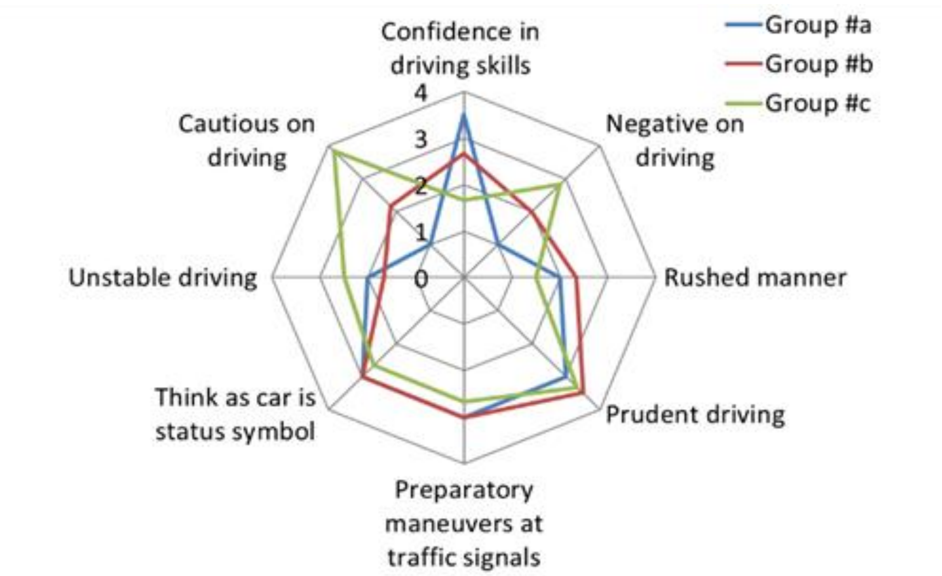


Fig. 6 Intersection right turn condition Driving characteristics of each group (n=15 subjects for right turning at intersection)

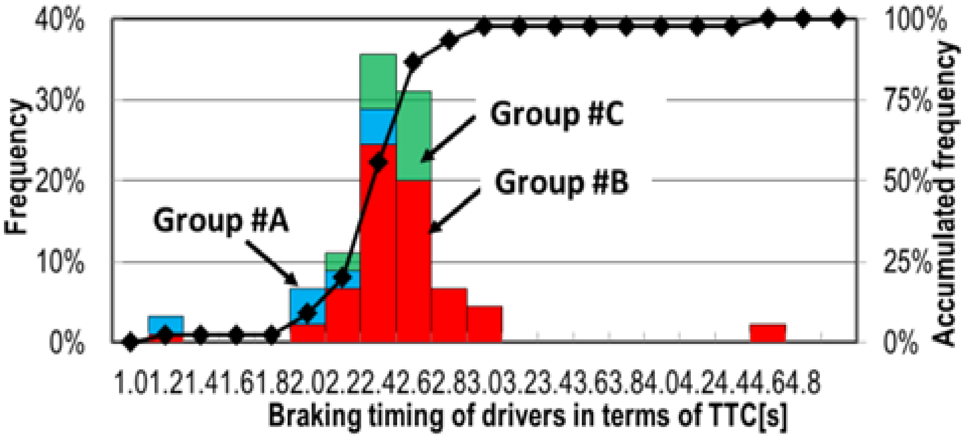
4.2. Start Timing to Apply the Brake for Each Driver Group

The start timing to apply brake for each group is shown in Fig.7 and Fig.8. The start timing for applying the brake on a straight road and right turning at an intersection is indicated by the frequency distribution and cumulative frequency distribution of TTC. Frequency distribution and cumulative frequency distribution of the lateral and relative distances are also given for reference. From these results, start timing of applying the brake for Group #A (very confident of driving skills) can be observed to be slightly late (brake is not applied until the TTC value is very small).

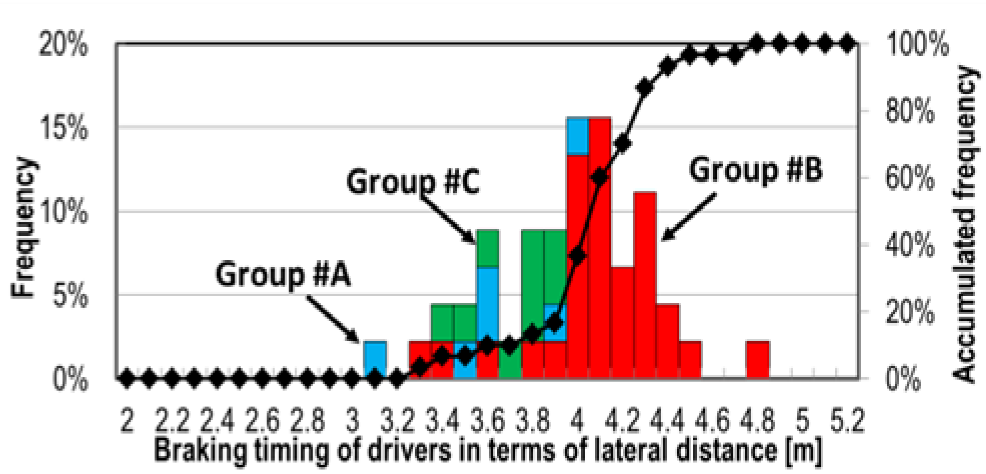
From the above, we concluded that the drivers of Group #A tend to be slightly late in applying the brake, and we need to set up the unified braking control timing including these driver categories. Using the cumulative frequency distribution of the start timing of applying the brake by all the 15 subjects, the start timing for braking control by the system was set.

Starting from the lower side of the median, we focused on the 1 st percentile, 5th percentile, and 50th percentile of braking operation timing of drivers. As shown in Table 2, four timings, namely these timings and the physical avoidance limit (friction coefficient of the road surface $\mu = 0.7$) was set as the start timing for braking by the system. The degree of interference between the driver and system operations was experimentally analyzed in the experiments conducted using the driving simulator.

An interesting point observed was that the start timing of applying the brake expressed in terms of TTC was almost same for the two driving environments, straight road and right turn at an intersection.

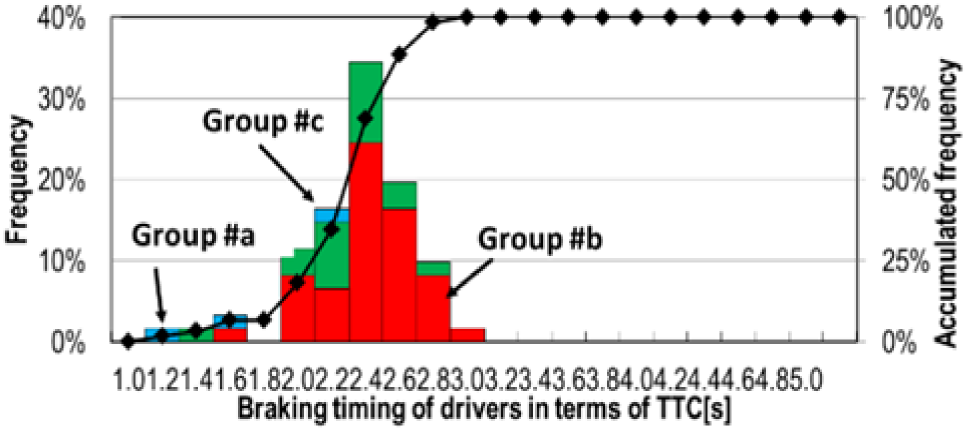


(a) Frequency distribution of TTC [s] in the longitudinal direction

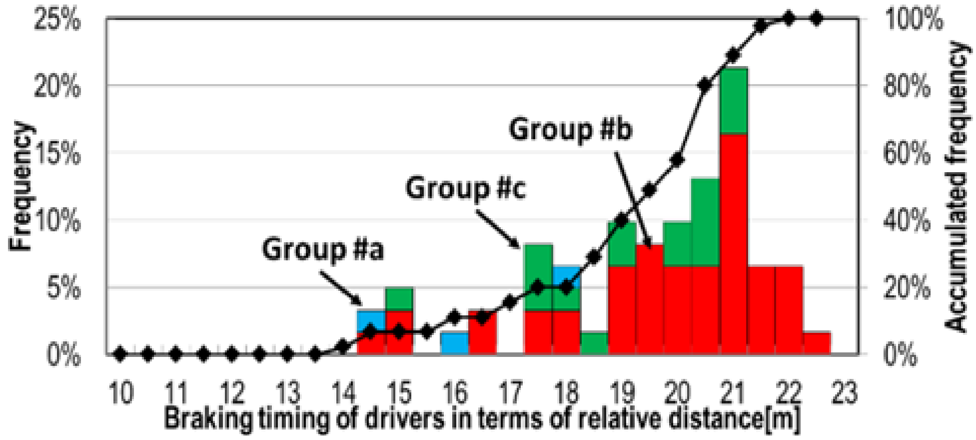


(b) Frequency distribution of buffer distance in the lateral

Fig. 7 Start timing of applying the brake of drivers for straight road



(a) Frequency distribution of TTC [s] in the longitudinal direction



b) Frequency distribution of relative distance

Fig. 8 Start timing of applying the brake of drivers for right turn at intersection

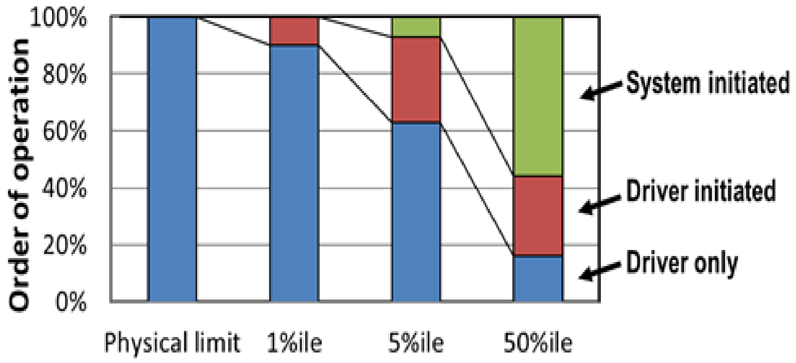
Table 2Start timing for braking control by the system

	Straight road **TTC, Lateral distance**	**Right turning at intersection** **TTC, Relative distance**
Physical limit	0.81s, 1.9m	0.41s, 5.2m
1st percentile	1.2s, 3.1m	1.2s, 14.8m
5th percentile	1.7s, 3.3m	1.6s, 16.2m
50th percentile	2.4s, 4.1m	2.2s, 20.0m

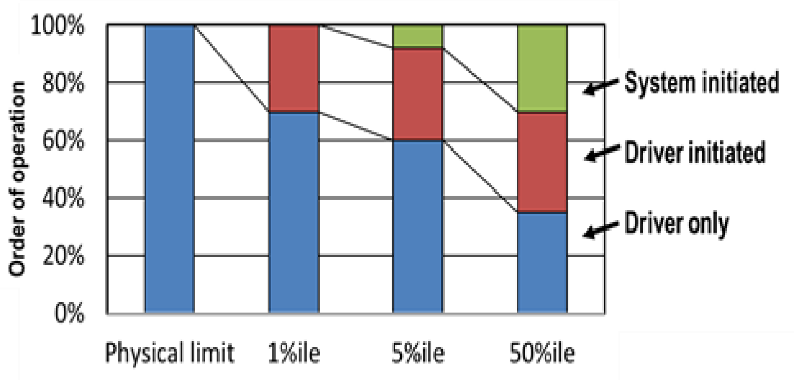
4.3. Interference between System and Driver Operations

We analyzed the interference and sequence of operations between the braking control by the system and braking operation by the driver. As shown in Fig.9, for the case of physical avoidance limit where the start timing for braking control was the latest, all the drivers avoid collision only by applying the brake themselves, both for the straight road and right turn at an intersection, and the system does not come into operation. In the lower 1st percentile of the driver operation, the system came into operation at some drivings in both the driving environments, but all the drivers apply the brakes first and there is no operation interference between the system and driver.

On the other hand, in the lower 5th percentile of driver operation and 50th percentile of driver operation, the system was confirmed to perform braking control before the driver at some drivings. There is a possibility that the driver may over-trust the system in such a state. To control system interference with the driver operation to prevent overconfidence, braking control must be at least in the lower 1st percentile of the driver operation.



(a) Straight road

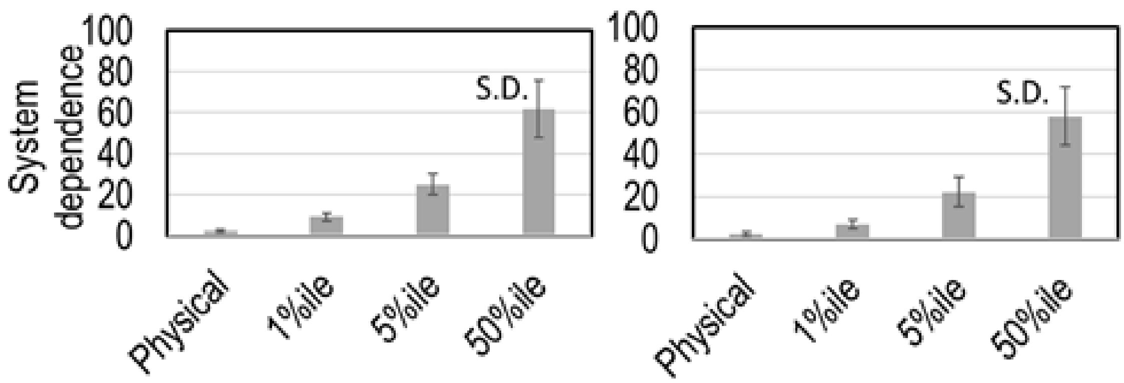


(b) Right turning at intersection

Fig.9 Interference of braking between system and driver

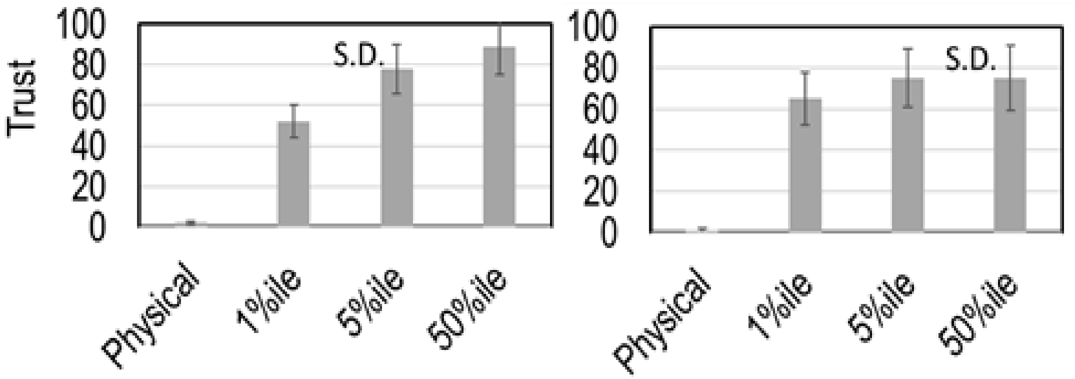
According to the survey on the braking start of the driver shown in Fig. 7 and Fig. 8 above, it was found that the braking operation timing of the drivers classified as Group # A and Group # a (very confident of driving skills) was delayed. Regarding these driver groups, we may think that braking by the system would be faster than the driver. However, in the case where the braking control timing of the system was set to the lower limit of 1% of the braking timing for all drivers, operation interference of braking between the driver and the system did not occur.

The 15 subjects were requested to respond to a questionnaire for the subjective evaluation of dependence on and trust of the system. The results are shown in Fig. 10. In this evaluation, we used the visual analogue scale for the subjective evaluation. As shown in the figure, setting the start timing for braking control by the system in the lower 1st percentile of the driver operation can be effective in reducing the degree of dependence while maintaining the level of trust in the system.



Straight road   Right turning at intersection

(a) Degree of dependence on the braking control by the system



Straight road Right turning at intersection

(b) Trust of start timing of braking control by the system

Fig.10 Questionnaire based subjective evaluation of dependence and trust

V. COMPARISON WITH START TIMING OF APPLYING BRAKE IN REAL TRAFFIC ENVIRONMENT

We will compare the start timing of applying the brake by the drivers that was analyzed using the driving simulator with the start time of braking in actual traffic environment to find out if there is a difference. The authors analyzed and compared the start timing of applying the brake by the drivers based on the videos from the drive recorders and CAN data of vehicles from the research conducted by authors in Japan and other countries in Europe, Asia, and North America. The comparison was carried out only for straight roads as a high volume of drive recorder data was available.

Data in which TTC was calculated based on detection of targets other than pedestrians, and data in which the driver applied brakes in response to targets other than pedestrians were excluded. The final data collected was used for comparison. Fig. 11 shows the comparison between the start timing of applying the brake in the real environment and start timing of applying the brake in the driving simulator of Fig. 7(a) given above.A significant difference was not observed (t-test) between the mean values was conducted for the distribution shape of both. This result shows that though a driving simulator was used in this survey, braking operation in the actual traffic environment can be analyzed.

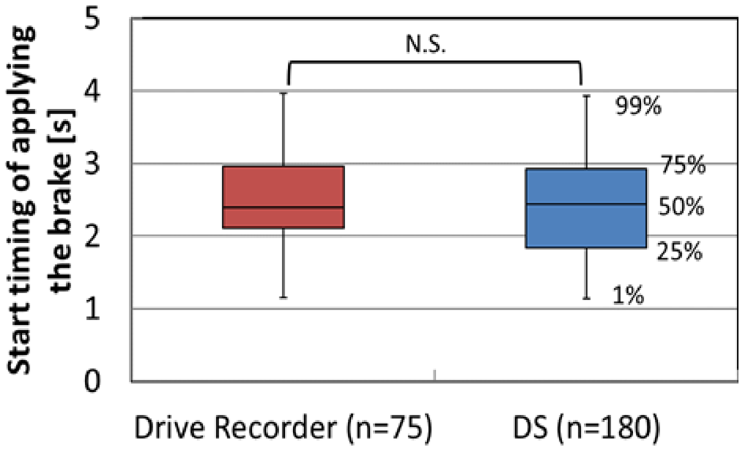


Fig.11 Comparison of start timing of applying the brake by drivers in real environment and driving simulator

VI. SUMMARY

6.1. Analysis of Start Timing of Applying the Brake by the Drivers

For straight roads, TTC in the longitudinal direction and lateral distance between the vehicle and pedestrians were analyzed as the evaluation indices. The start timing of applying the brake for 15 subjects was as follows.

Straight road (40km/h)

1 st percentile TTC=1.2s, Lateral distance =3.1m
5th percentile TTC=1.7s, Lateral distance =3.3m
50th percentile TTC=2.4s, Lateral distance =4.1m

Right turn at intersection (20km/h)
1 st percentile TTC=1.2s, Relative distance =14.8m
5th percentile TTC=1.6s, Relative distance =16.2m
50th percentile TTC=2.2s, Relative distance =20.0m

There was no difference between the start timing of applying the brake obtained in the study using a drive recorder and start timing of applying the brake obtained using the driving simulator, and this shows that the braking operation in the real environment could be reproduced in the experiments conducted using the driving simulator.

6.2. Analysis of Operational Interference between Driver and System, and Relationship between Dependence and Trust

When braking control was started at the brake timings corresponding to the above 3 levels and physical avoidance limit, driver applied the brake before braking control by the system at a timing corresponding to the lower 1st percentile.

From the investigation results of the subjective evaluation of dependence and trust in the system, the tendency to maintain high trust while reducing the degree of dependence was confirmed at a timing corresponding to the lower 1st percentile.

REFERENCES

[1]. DIGITAL TRENDS, Who pays for autonomous driving fatalities? , *https://www.digitaltrends.com/cars/autonomous-driving-fatalities-get-the-attention-of-auto-insurance-companies*
[2]. John Lee, Neville Moray, Trust, control strategies and allocation of function in human machine systems, *Ergonomics journal, Vol.35, No.10*, 1992, 1243-1270.
[3]. Makoto Itoh, Toward Highly Reliable System Preventing Overtrust, *Journal of Reliability Engineering Association of Japan, Vol.25, No.4*, 2003, 354-360.
[4]. Keisuke Suzuki, Yoshitaka Marumo, A Study on the Onset Timing of Collision Avoidance Assistance Systems for Minimizing the Over-reliance on the System, *Transactions of the Japan Society of Mechanical Engineers. C 69(688)*, 2003, 3236-3242.
[5]. *https://www.itarda.or.jp/materials/report_summary.php?q=877&p=h2401/h24-01.html*
[6]. MachikoHiramatsu, KenjouUmezaki, Analysis of Pedestrian Accident Scenarios based on Driver and Pedestrian Behavior, *Transactions of Society of Automotive Engineers of Japan 36(4)*, 2005, 225-229.
[7]. Ryo Iwaki, Takashi Wakasugi, Edgar Yoshio Morales Teraoka, Shin Tanaka, Nobuyuki Uchida, Analysis of Driver Response to Road Crossing pedestrian, *Proceedings of JSAE conference, No.146*, 2013, 21-26.
[8]. Ryo Iwaki,HisashiImanaga,Iori Yamaguchi, Nobuyuki Uchida, Driving Behavior for Avoiding Road Crossing Pedestrian at Non-Intersection Area,*Proceedings of JSAE conference, No.35*, 2015, 822-827.
[9]. HisashiImanaga, Ryo Iwaki, Iori Yamaguchi, Nobuyuki Uchida, Driving Behavior for Avoiding Road Crossing Pedestrian at Non-Intersection Area(Second Report), *Proceedings of JSAE conference, No.35*, 2015, 828-833.
[10]. RyutaFutagami, Hiroshi Mouri, RyukiTsuboi, Factor Analysis and Consider Measures of Pedestrian Accidents at Right Turn in the Intersection that Have Traffic Lights,*Proceedings of JSAE conference, No.189*, 2017,1042-1045.
[11]. MotonoriIshibashi, Ryo Yamashita, Ichiro Kageyama, Development of Performance Test for Attention Allocation Ability in Right Turn at Intersection, *Proceedings of JSAE conference, No.094*, 2017, 522-527.
[12]. Naoji Matsumoto, Shinya Kiyota, Miho Ito, Relationship between the Characteristics of Streets and walking speed, *Transactions of AIJ. Journal of architecture, planning and environmental engineering, 74(640)*, 2009, 1371-1377.
[13]. *http://www.nsgk.co.jp/sv/kensa/kraepelin/*
[14]. MotonoriIshibashi, Masayuki Okuwa, Shun'ichiDoi, MotoyukiAkamatsu, Characterizing Indices of Driving Style and their Relevance to Car Following Behavior, *JSAE Transaction, Vol.39, No.1*, 2008, 121-126.