Influence of Deceleration Intention Indicating System of Forward Vehicle on Driver Behavior

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Abstract. This paper discusses a way to detect the driver's intention to decelerate the vehicle in a car-following situation. In the present study, a field observation of a car driving and an experiment were conducted. In the field observation, the data were collected for analyzing a driver's maneuvering of the accelerator and brake pedals in order to design a system that can detect the driver's intention to deceleration. The method based on the covering brake pedal found to be highly reliable. In the experiment, an investigation using an experimental vehicle and a test course was conducted to evaluate the influence of the proposed system on the driver behavior. The experimental results showed that the system was effective in improving the driver's accelerator release time (ART) and the brake onset time (BOT).

Keywords: Safety, Intelligent vehicle, Driver support, Driver behavior.

1 Introduction

Recently, technologies for preventing road traffic crashes have been actively developed worldwide. Rear-end collisions are one of the most common type of accidents. Today's intelligent and autonomous automobiles, are equipped with many sensors and computers, and they can sense and analyze situations, decide what must be done, and implement control actions. Examples of such systems include the Forward Collision Warning System (FCWS) [1-2] and Collision Avoidance System (CAS) [3]. FCWS provides warnings to encourage a driver to take appropriate actions to avoid a crash, and is to enhance a driver's situation awareness [4]. If the driver does not take appropriate action after the warning is issued, CAS performs a control intervention on behalf of a human, and is to trade a control authority in emergency. These Advanced Driver-Assistance System (ADAS), which is installed in a vehicle, adaptively interact with and assist the driver in a situation-adaptive manner [5].

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Furthermore, studies have also focused on methods to improve the interaction between the vehicles in car-following situations. For example, the Emergency Stop Signal (ESS) [6] enhances the situation awareness of a following driver about the forward vehicle's behavior. Saffarian and Happee [7] proposed a car-following assisting system named as Rear Window Notification Display (RWND) for effective interaction between vehicles under normal driving situations. Its interface quantifies the acceleration and time-headway (THW) of the instrumented forward vehicle. These ADAS interacts between the vehicles and helps redirect the driver's visual glance and pays the attention to forward roadway. Saito et al. [8] have proposed a deceleration intention indicating system, which indicates a driver's intention to decelerate the vehicle in advance. This system was developed for effective interaction between vehicles in car-following situations. Where RWND indicates the acceleration and THW based on the vehicle's data such as the acceleration, the proposed system indicates the same by judging the driver's intention to decelerate based on his/her actual maneuver. This system has been developed to enhance a driver's situation awareness.

This paper discusses a way to detect the driver's intention to decelerate. In the present study, a field observation of a car driving and an experiment were conducted. In the field observation, the driving performance data were collected for analyzing the state of his/her maneuver of the accelerator and brake pedals in order to design a system that can detect the driver's intention to decelerate. In the experiment, an investigation using an experimental vehicle on a test course was conducted to evaluate the influence of the deceleration intention indicating system on the driver behavior.

2 System Concept

In situations where a vehicle is following another, such as in traffic, the deceleration intention indicating system indicates the driver's intention to decelerate of the forward vehicle before the braking maneuver is actually initiated. The system aims to improve the following driver's predictions and expectations regarding the forward vehicle's behavior, and to reduce the risk of a rear-end collision by impelling the following driver to decelerate early. The system consists of an auxiliary stop lamp, which is installed on the rear window of the forward vehicle. According to the domestic preservation standard in Japan, a stop lamp is obliged to operate by a consecutive lighting of a red light. A following driver reacts to the lighting of the stop lamp reflectively based on his/her experiences and educations. The proposed system serves as an auxiliary stop lamp, and its operation is indicated by a consecutive lighting of a yellow light. The lighting of a stop lamp generally indicates braking, but the auxiliary stop lamp in this system indicates the driver's intention to decelerate.

Judgment on Presence or Absence of Driver's Deceleration Intention. In this study, we have attempted to judge whether the driver's intention to decelerate based on his/her actual maneuvering of the brake and accelerator pedals. The following situations were considered.

1. Accelerator off (accelerator output is 0%).
2. Presence or absence of the driver's foot above the accelerator pedal.
3. Presence or absence of the driver's foot above the brake pedal.

These situations are useful to judge the driver's intention to decelerate. The system can determine that a certain behavior indicates the driver's intention to decelerate because the vehicle slows down with the driver's maneuver. However, if the system were to assume that a driver hits brake only when he/she intends to decelerate, the judgment will be not reliable enough. For example, when a driver implements the accelerator off, he/she may implement so for maintaining speed. In this case, the brake maneuver is not implemented. This is because the information may be indicated before the driver decides about implementing a brake maneuver or because a driver may change the decision-making based on traffic conditions after having finished decision-making about the brake maneuver. First, field observations of the experimental vehicle being driven were performed to analyze the driver's maneuvering of the accelerator and brake pedals.

3 Data Collection

3.1 Method

Apparatus. The experimental vehicle (Toyota Progress 2,500cc) used in the field observation can measure the state of maneuver of the accelerator and brake pedals.

Participants and Driving Task. Two drivers (two male) aged 26 and 45 have participated. The participants are researchers from the National Institute of Advanced Industrial Science and Technology (AIST). The participants hold a valid driver's license and drive daily. Their task was to drive safely on public-roads in Tsukuba-city. The participants drove a specified course freely (length: approximately 13km).

Measures. The driving data collected in the study were the speed (km/h), acceleration (G), inter-vehicle distance (m) (measured with the laser sensor), GPS-time (s), displacement of the accelerator and brake pedals, and presence or absence of the driver's foot above the accelerator or brake pedals (ON/OFF). The frequency of data collection was 30Hz. The "Cover accelerator pedal" (Cover AP) refers to the presence or absence of the driver's foot above the accelerator pedal and "Cover brake pedal" (Cover BP) refers to the presence or absence of the driver's foot above the brake pedal. The experimental vehicle was equipped with the electronic photo sensors in order to detect the presence or absence of the driver's foot above these pedals (Fig.1).

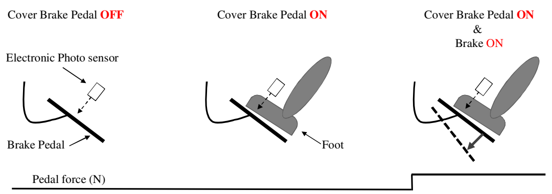

Fig. 1. Specific of Cover BP ON/OFF (Cover AP is detected in a similar manner.)

3.2 Results and Discussions

An analysis of the state of maneuver of the accelerator and brake pedals was performed on the following items. The calculated item shows the time to indicate the driver's intention to decelerate and the credibility of the system's indication.

- Time to implement the brake maneuver from implementing the "Accelerator OFF", "Cover AP OFF", and "Cover BP ON" maneuver.
- Rate of actual implementing the brake maneuver after implementing the "Accelerator OFF", "Cover AP OFF", and "Cover BP ON" maneuver.

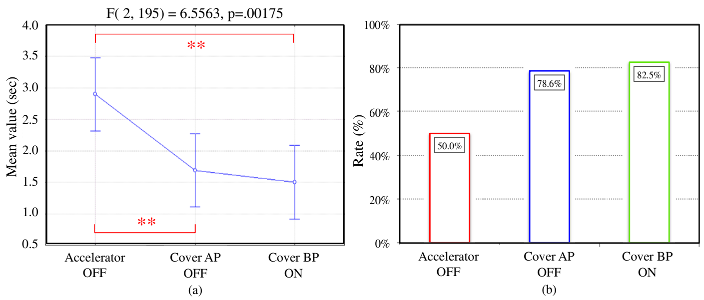

Fig. 2. (a): Time to implement the brake maneuver from implementing each behavior, (b): Rate of implementing the brake maneuver after implementing each behavior (**$p<0.01$, *$p<0.05$)

As seen in Fig.2 (a), the time to implement the brake maneuver from implementing the "Accelerator OFF" was the longest with 2.9 s as the mean value, and the time to implement the brake maneuver from implementing the "Cover BP ON" was the shortest with 1.5 s as the mean value. On the other hand, as seen in Fig.2 (b), the rate of actual implementing the brake maneuver after implementing the "Accelerator OFF" was the lowest (50.0 %), and the rate of actual implementing the brake maneuver after implementing the "Cover BP ON" was the highest (82.5 %). Additionally, as a result of having performed analysis of variance (ANOVA) on the time to implement the brake maneuver from implementing each behavior, the main effect was highly statistically significant ($F(2, 195)=6.5563, p<0.01$). According to Tukey's HSD test, significant differences were found between "Accelerator OFF" and "Cover AP OFF", and between "Accelerator OFF" and "Cover BP ON".

Summarizing these results, when the system judges the driver's intention to decelerate by detecting the "Accelerator OFF", the time when the information is indicated before the braking maneuver is actually initiated was the longest, but the rate of actual implementing the brake maneuver after implementing the "Accelerator OFF" was the lowest. In other words, the credibility of the information indicated by the system when it judges the driver's intention to decelerate was the lowest. When the system judges the driver's intention to deceleration by detecting the "Cover AP OFF" or "Cover BP ON", no significant differences were found in the time when the information is indicated before the braking maneuver is actually initiated. The credibility of the information indicated by the system was higher when it judges the driver's intention to decelerate based on "Cover BP ON" than when it judges the same based on "Cover AP OFF". From these results, when the system detects the driver's brake maneuver intention based on each behavior listed above, the judgment was not reliable enough. In the present study, we have designed a system that bases its judgment of the driver's intention to deceleration on Cover BP in order to make the judgment more reliable. That is, the system judges that the driver intends to decelerate when his/her foot is above the brake pedal.

The time taken to indicate the driver's intention to decelerate was less than 2 s occupy most in approximately 70% of the case. The most frequent value was less than 0.5 s, and it occurred in 37.9% of the case. The time taken by the system to convey the driver's intention to decelerate was between 0.5 and 1 s, 1.0 and 1.5 s, and 1.5 and 2.0 s in 22.7%, 9.1%, and 9.1% of the cases, respectively. The time taken depends on the traffic conditions and the driving attitude of the driver. Assuming the situation where the auxiliary stop lamp turns on for approximately 1.0 s before the braking maneuver is actually initiated, improving the following driver's predictions and expectations regarding the forward vehicle's behavior is needed.

4 Experiment

The purpose of the experiment is to clarify the following points: (1) effect of the system, and (2) influence of the system on the driver behavior. The following working hypothesis is made: the system improves the following driver's predictions and expectations by indicating the driver's intention to decelerate in the forward vehicle. Therefore, the following driver can prepare to take an appropriate action for the deceleration in advance, and the system can impel the driver to decelerate early.

4.1 Apparatus

By using two experimental vehicles, we recorded the data for the same items as in the field observation. In addition, the measurement items of two vehicles were synchronized by GPS time (Fig.3). Further, the forward vehicle's acceleration and deceleration were controlled the automatically in order to ensure the reproducibility. Therefore, the forward vehicle had automated speed control (Mazda Millenia 2,500cc), and the following vehicle (Toyota Progress 2,500cc) was the experimental vehicle used to measure the driver behavior.

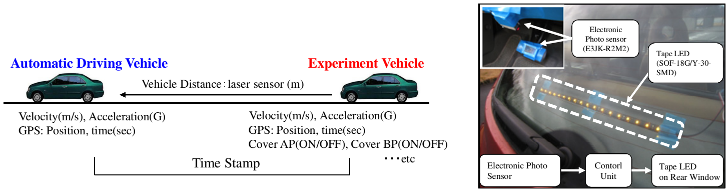

Fig. 3. Experimental vehicle and set-up

The system was set up with the auxiliary stop lamp on the rear window of the automated vehicle (Fig.3). It was indicated via a Tape LED (SOF-18G/Y-30-SMD), and a reflection plate (E3JK-R2M2) was installed on the brake pedal. When the electronic photo sensor detects that the driver has put their foot above the reflector plate, the auxiliary stop lamp is turned on. In this experiment, it was indicated by the program automatically in order to ensure the reproducibility. The indicating time was set 1.0 and 1.5 s. It was designed based on the results of the field observation.

4.2 The Participants, Driving Task, and Procedure

Four drivers (four male) aged 23 - 45 have participated in the experiment. The participants are researchers from AIST. The participants hold a valid driver's license and drive daily. A driving task was to drive safely in the cruising lane in a car-following situation. The experiment was performed on the test track of AIST. The experimental course is an oval course (3.2km). The forward vehicle kept driving on the same lane. Other vehicles were not allowed to enter the test course. The speed profile of the automated vehicle (forward vehicle) is shown in Fig.4. It was designed with reference to 10・15 and JC08 mode, which is used to evaluate fuel efficiency in Japan.

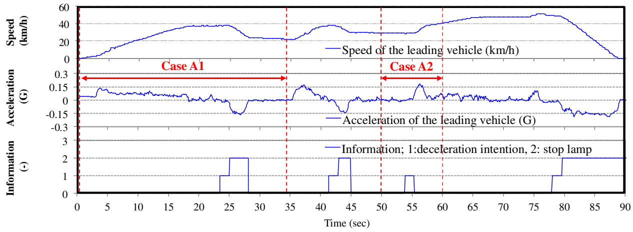

Fig. 4. Driving profile of automated vehicle

This experiment consisted of four sessions. The 1st session was a short introduction session of approximately 6.0 min. In the 2nd session, the participants drove without the proposed system. It was performed repeatedly four times. In the 3rd session, the participants drove at the support condition as described in the next subsection. It was also performed repeatedly four times. In the 4th session, the participants drove again without the proposed system (baseline condition). It was also performed repeatedly four times. Before the 1st session, the participants were instructed about the operation, test procedure and driving task. The systems' interface was also explained.

4.3 Independent Variable

Driving condition was the within subject variable. Two conditions were distinguished as follows:

1. Support condition: The system indicates the driver's intention to decelerate of the forward vehicle before the braking maneuver is actually initiated.
2. Baseline condition: No support function is available.

4.4 Dependent Variable

The data collected were the speed (km/h), acceleration (G), inter-vehicle distance (m), GPS-time (s), displacement of the accelerator and brake pedals (mm), and Cover AP/BP (ON/OFF). Additionally, the following items were calculated:

- The relative speed between the vehicles.
- The Time-Headway between the vehicles (THW).
- The inverse of TTC between the vehicles (iTTC).
- Time to release the accelerator from forward vehicle initiated slowdown (ART).
- Time to implement the brake from forward vehicle initiated slowdown (BOT).
- Time to implement the brake maneuver from Cover BP ON (MT).
- Time to implement to accelerate from forward vehicle initiate to accelerate (AOT).

4.5 Scenario

The scenario in the experiment consisted of two events, named A1 and A2 (Fig.5).

- A1: Vehicle B maintains as speed of 40km/h for 6 s. After that, vehicle B slows down to 20km/h at 0.15G. Then, the driver's intention to decelerate is indicated for 1.5 s before vehicle B slows down.
- A2: Vehicle B maintains as speed of 30km/h for 10 s. Then, the driver's intention to decelerate is indicated for 1.0 s. After that, vehicle B accelerates without slowing down.

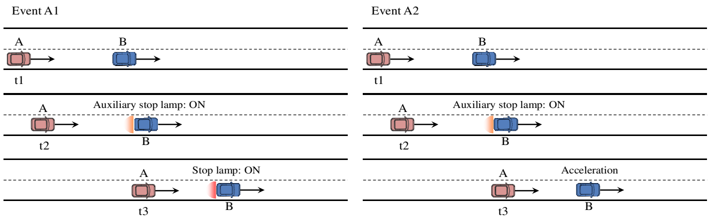

Fig. 5. Event A1 and A2

4.6 Results

The experimental results of session 3 (support condition) were compared with those of session 4 (baseline condition). The data of one participant (participant no.4) was excluded in the analysis data, because how to get inter-vehicle distance changed and it was difficult to compare between conditions. Furthermore, when there was an unintended acceleration of the automated vehicle, the data was excluded. In this experiment, there was once unintended acceleration.

Event A1. Table 1 shows the driving performance metrics. In this analysis, we performed a t-test on each value. Several significant differences were found, and these were found for the minimum of relative speed ($p<0.05$) and the maximum of acceleration ($p<0.01$). A marginally significant difference was found in iTTC ($p<0.1$). These results showed that the relative speed and the maximum acceleration were suppressed by indicating the driver's intention to decelerate.

The results of the t-test on ART and BOT are shown in Figs.6 and 7. Significant differences were found in the mean of ART ($p<0.01$) and BOT ($p<0.05$). ART was -0.68 (SD: 0.47) s at the mean value in the support condition. As a result of the driver having prepared early for the deceleration, BOT was 0.23 (SD: 0.82) s at the mean value in the support condition, and it improved to 0.63 s at the mean value compared with the baseline condition. ART and BOT were improved by the system, and the slowdown behavior of the following driver was quick. The results of the t-test on MT are shown in Fig.8. Significant differences was found in MT ($p<0.05$). MT was 0.61 (SD: 0.44) s at the mean value in the support condition, and it was 0.23 (SD: 0.11) s at the mean value in the baseline condition. Therefore, the results showed that the following driver could prepare to take appropriate action for the deceleration in advance.

Table 1. Driving performance, mean (SD)

	Min Relative speed (m/s)	Max Acceleration (G)	Max Displacement of brake pedal (mm)	Min THW (sec)	Max TTC^{-1} (1/sec)
Without-system	-2.31(0.376)	-0.25(0.036)	33.74(3.006)	1.365(0.256)	0.175(0.028)
With-system	-1.66(0.638)	-0.18(0.037)	31.92(2.185)	1.355(0.298)	0.146(0.037)
p < (Without-system vs With-system)	**0.01214**	**0.00026**	0.104	0.96985	0.0534

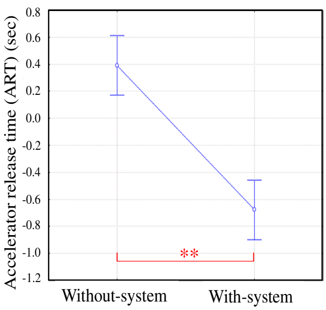

Fig. 6. ART

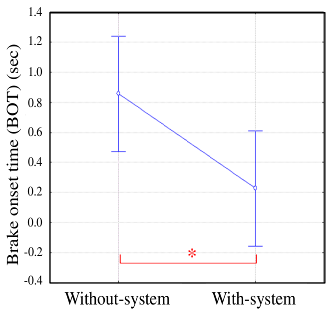

Fig. 7. BOT (**p<0.01, *p<0.05)

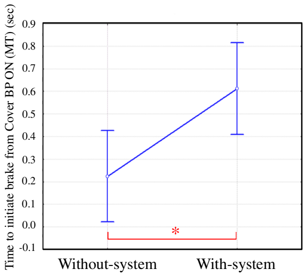

Fig. 8. MT

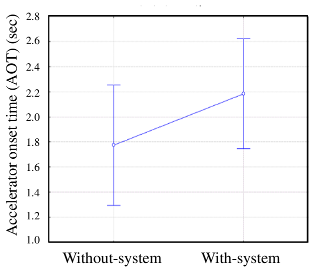

Fig. 9. AOT (**p<0.01, *p<0.05)

Event A2. The results of the t-test on AOT are shown in Fig.9. No significant differences were found in the mean value of AOT. If the forward vehicle initiates to accelerate, the following driver's acceleration maneuver may be late, because the system does not provide any information about the forward vehicle's acceleration. If the delay is large, there is a possibility that the traffic flow will be affected. The result claims that the impact on the traffic flow by the system is small in case of event A2.

4.7 Discussions

The system indicated the driver's intention to decelerate before the braking maneuver is actually initiated. This gave the following driver predictions and expectations regarding the forward vehicles' behavior in the near future. The system offers a support in order to improve the following driver's predictions and expectations regarding the traffic conditions that may occur in the next few seconds as well as those regarding other road users' actions. In other words, the system enhances the situation awareness of a following driver. Situation awareness can be classified into three levels [4]: Level1: perception of elements in the environment, Level2: comprehension of current situation, and Level3: projection of future status. The system helps the driver to attain situation awareness levels 1, 2, and 3. In event A1, the system gave an opportunity to utilize the driver's intention to decelerate as a means to improve the following driver's prediction of the vehicle's upcoming behavior. These predictions can be used to adjust the timing of actions and to implement the actions. From the result of ART in Fig.6, the following driver released the accelerator pedal before the brake maneuver of the forward vehicle is actually initiated. The results showed that the system was effective in improving ART and BOT of the following driver. In addition, the system was effective in providing some safety margins because the following driver could prepare to take an appropriate action for the deceleration in advance (Fig.8). From the above, the driver, assisted by the proposed system, could prepare for the deceleration in advance by recognizing the driver's intention to decelerate and predicting the vehicle's upcoming behavior. Enke [9] showed that an improvement of the driving behavior has the same effect as a maneuver to avoid a crash, which is started a few tenths of a second earlier. It estimated that it could evade the half by an improvement of 0.5 s for the correspondence of driver in the rear-end collisions. Therefore, the effect of the mitigation or avoidance of rear-end collisions is needed by using the deceleration intention indicating system.

5 Concluding Remarks

This paper discussed a way to detect the driver's intention to decelerate in a car-following situation. In the present study, a field observation and experiment were conducted. In the field observation, the driving performance data were collected for analyzing the state of the following driver's maneuver of the accelerator and brake pedals in order to design a system to detect the driver's intention to decelerate. The method based on the covering brake pedal was shown to be most reliable in judging the driver's intention to decelerate of the forward vehicle. In the experiment, the experimental results showed that the system was effective in improving the following driver's ART and BOT, and it provided some safety margins because the following driver could prepare to take an appropriate action for the deceleration of the forward vehicle in advance.

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