ABSTRACT: This study proposes a driver assistance system that provides an appropriate pedal operation by considering information on the pre-preceding vehicle. The system calculates the risk of collision by taking into account not only the preceding vehicle, but also the pre-preceding vehicle ahead of the preceding car. The computed numerical risk is then translated into the visual interface that assists the driver to make an appropriate acceleration and deceleration in car-following. Several participants who participated in driving simulator experiments were instructed to follow a preceding as well as a visible pre-preceding vehicles with and without the driver assistance system. It was found that the assistance system succeeded in reducing the relative velocity with the pre-preceding vehicle and in eliminating the unnecessary acceleration and deceleration of the following vehicle. Safety and fuel economy were also significantly improved by introducing the proposed system.

KEY WORDS: safety, active safety, driving support, pre-preceding vehicle, predicted driving behavior, following characteristics, pedal operation [C1]

1. Introduction

Driver assistance systems, which encourage drivers to improve their driving behavior by indicating driving information to drivers, have been developed and commercialized. A fuel economy meter and the indication of collision risk are well known as the fundamental measures for drivers to make an eco-friendly (1)(2) and safe driving (3)(4). In order to improve the fuel economy and to minimize the collision risk to the preceding vehicle, the driver should predict appropriate driving behavior such as the earlier deceleration by using the information on the ahead of the preceding vehicle.

It is obvious that the fuel economy depends on the vehicle states and drivers’ characteristics. Earlier release of gas pedal by utilizing the information on the behavior of preceding vehicle is effective to improve the fuel economy (5). In addition, the collision risk to the preceding vehicle depends on the relation between the preceding and following vehicles. However, if the preceding vehicle shows an inappropriate behavior, suppressing the collision risk to the preceding vehicle does not contribute to safety driving (6). Therefore, predicting appropriate driving behavior of the following vehicle is more important by using the information not only on the preceding vehicle but also on the pre-preceding vehicle.

Recently, the assistance system, which alerts the occurrence of emergency deceleration of the pre-preceding vehicle, to the driver has been developed (7).

This study proposes the evaluation index to predict appropriate driving behavior by using the information not only on the preceding vehicle but also on the pre-preceding vehicle. The driving simulator experiments were carried out to evaluate the driver assistance system that encourages an appropriate longitudinal driving behavior by indicating the proposed evaluation index to the driver in real-time.

2. Evaluation Index of Predicted Driving Behavior

A three-car platoon which consists of pre-preceding (1st), preceding (2nd) and the following (3rd) vehicles is assumed as depicted in Fig.1. Denoting i as the vehicle number, $v_i$ and $d_{i+1}$ are defined as the velocity of the $i$th vehicle and the headway distance between the $i$th and the $(i+1)$th vehicles. For example, $d_{23}$ corresponds to the headway distance between the preceding and the following vehicles.

![Fig. 1 Three-car platoon.](image-url)
One of the evaluation indices for the collision risk to the preceding vehicle is the Risk Perception (RP). The RP is defined as the weighted sum of the inverse of Time To Collision (TTC) and the inverse of the Time HeadWay (THW) as defined in Eq. (1). This index represents the driver’s subjective risk to the preceding vehicle.

\[
RP = \frac{a}{THW_{23}} + \frac{b}{TTC_{23}} = \frac{av_1}{d_{23}} + \frac{b(v_5 - v_3)}{d_{23}}
\]  

(1)

Here, THW\textsubscript{23} and TTC\textsubscript{23} are the time headway and the time to collision of the following (3\textsuperscript{rd}) vehicle to the preceding (2\textsuperscript{nd}) vehicle, respectively. Coefficients \(a\) and \(b\) are equal to 1 and 5 according to the study by Kondoh, et al.\textsuperscript{(9)}.

The proposed evaluation index for the predicted driving behavior considering the pre-preceding (1\textsuperscript{st}) vehicle is based on the RP. Suppressing the relative velocity to the pre-preceding vehicle reduces the unnecessary acceleration and deceleration. Therefore, TTC, which is effected by the relative velocity, is applied to the pre-preceding vehicle. In addition, in order to prevent the collision to the preceding vehicle, THW is still applied to the preceding vehicle. The coefficient \(b\) in Eq. (1) is twice because the TTC, which is proportional to the headway distance, is applied to the pre-preceding vehicle. The novel index, which is referred to as the PRE\textsubscript{3} (PREdiction by PRE-PREceding vehicle), is defined as follows;

\[
PRE_3 = \frac{a}{THW_{23}} + \frac{2b}{TTC_{13}} = \frac{av_1}{d_{23}} + \frac{2b(v_5 - v_3)}{d_{13}}
\]  

(2)

where TTC\textsubscript{13} is the time to collision of the following (3\textsuperscript{rd}) vehicle to the pre-preceding (1\textsuperscript{st}) vehicle.

### 3. Driving Simulator Experiments

#### 3.1. Experimental Method

In order to examine the effects of the driver assistance system by indicating the PRE\textsubscript{3} to the driver in real time, the driving simulator experiments are conducted. Experimental participants are required to follow the two vehicles, i.e. a pre-preceding and a preceding vehicles, with and without the assistance system. This study uses the CarSim DS 8.1.1 (Mechanical Simulation Corporation)\textsuperscript{(10)} as shown in Fig. 2 for the driving simulator experiments.

The velocity pattern of the pre-preceding and preceding vehicles are assumed as shown in Fig.3. The pre-preceding vehicle repeats the acceleration and deceleration with 1m/s\(^2\) and travels between 10m/s (36km/h) and 15m/s (54km/h). The following algorithm of the preceding vehicle to follow the pre-preceding vehicle is based on the PID control. The PID controller compensates the heaway distance error between the actual distance and the desired heaway distance, which is calculated by multiplying the vehicle velocity and the desired time headway (1.5s). The feedback gains for the PID control are adjusted to simulate the general driver’s following characteristics.

The driving course is a straight corridor. Oncoming vehicles appear at random during the experiments. The pre-preceding vehicle is a tall minivan and the preceding vehicle is placed at the

\[\text{Fig. 2 Overview of fixed-base driving simulator.}\]

\[\text{Fig. 3 Velocity profile of pre-preceding and preceding vehicles.}\]

\[\text{Fig. 4 Graphical image of PRE3 indicator.}\]
left side on the road to make the driver recognize the pre-
 preceding vehicle easily even without the assistance system.

Figure 4 illustrates the image of the PRE3 indicator. The bar
length and colors of the indicator correspond to the PRE3 value.
The bar colors consist of green, red and gray as shown in Fig.
4(b). The neutral value of the PRE3 is set to 0.5s⁻¹, and this value
means that the time headway to the preceding vehicle THW₂₃
is equal to 2s if the relative velocity to the pre-preceding vehicle
is 0m/s if the following vehicle velocity v₁ is slower than the pre-
 preceding vehicle velocity v₁ or the following vehicle is away
from the preceding vehicle (longer THW₂₃), the indicator bar
is extended downward and is colored in green. This is supposed to
encourage the driver to accelerate to increase the PRE3 value. On
the other hand, if the velocity of the following vehicle v₃ is faster
than that of the pre-preceding vehicle v₁ or the following vehicle
is close to the preceding vehicle (shorter THW₂₃), the indicator
bar is extended upward and is colored in red. The driver should
decelerate to reduce the PRE3 value. If the driver performs the
appropriate driving behavior, the indicator maintains the gray bar.

Nine males, whose ages ranged from 20 to 23 years old,
participated in the simulator experiments. Their driving
experiences are between nine and 34 months, with an average
experience of 22 months. All the participants gave their written
informed consent before the experiments. The test drive was
conducted to familiarize themselves with the simulator driving
and the behavior of the PRE3 indicator. The participants are to
experience the trials with the assistance system before the
experiments without the assistance. These two driving conditions,
i.e. with and without the assistance system, were repeated twice,
to make all four trials for each participant.

The participants were instructed to follow the rules and
regulations below; “Look at the pre-preceding vehicle behavior
carefully and predict appropriate driving behavior by the earlier
acceleration and deceleration.” “Drive the car so as to maintain
the indicator bar stay in the gray color.” “Even without the
assistance system, follow the two vehicles ahead just like your car
was equipped with the assistance system.” The last instruction is
given in order to evaluate the effect of the proposed system as
precise as possible.

3.2. Experimental Results

3.2.1. Driving behavior of following vehicle

Figure 5 illustrates an example of the speed variation of the
following vehicle (2nd trial by participant A). The solid line
indicates the following vehicle velocity with the assistance system
and the dashed line is without the assistance system. The driver
with the assistance system reacts the velocity change of the pre-
 preceding vehicle, while the driver without the assistance delays
his acceleration to the pre-preceding vehicle. The assistance
system prevents the delay of velocity change of the pre-preceding
vehicle and reduces the relative velocity to the pre-preceding
vehicle. This effect contributes the suppression of unnecessary
acceleration and deceleration.

The RMS of the relative velocity to the pre-preceding
vehicle is depicted in Fig. 6. This figure shows the average of 18
trials (total of the two conditions for the nine participants). The
assistance system reduces the RMS of the relative velocity to the

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**Fig. 5** Velocity of following vehicle (2nd trial by participant A).

**Fig. 6** RMS of relative velocity to pre-preceding vehicle.

**Fig. 7** Acceleration of following vehicle (2nd trial by participant A).

**Fig. 8** RMS of acceleration.
pre-preceding vehicle with a significant difference under the 1% confidential level. This means that the assistance system makes the driver recognize the velocity change of the pre-preceding vehicle and prevents the unnecessary acceleration and deceleration.

The acceleration variation of the following vehicle (2nd trial by participant A) is shown in Fig. 7. The line types are same as the Fig. 5. The acceleration response with the assistance system is earlier than that without the assistance system. In addition, the maximum and minimum acceleration are suppressed by the assistance system.

Figure 8 shows the RMS of the following vehicle acceleration, averaged by 18 trials. The assistance system reduces the RMS of acceleration with a significant difference under the 1% confidential level.

3.2.2. Evaluation indices

Figure 9 illustrates the PRE3 variation of the following vehicle (2nd trial by participant A). The driver with the assistance system maintains the PRE3 around 0.5s⁻¹, while the driver without the assistance system makes the PRE3 fluctuate around 0.5s⁻¹. The assistance system reduces the fluctuation of the PRE3.

Thought the mean of the PRE3 with and without the assistance system has no significant difference, its standard deviation shows the large variation as depicted in Fig. 10. The assistance system suppresses the standard deviation of the PRE3 with a significant difference under the 1% confidential level.

Figure 11 illustrates the Risk Perception variation of the following vehicle (2nd trial by participant A). The RP with the assistance system is maintained around 0.5s⁻¹, while the RP without the assistance system is fluctuated around 0.5s⁻¹. The RP fluctuation is also reduced by the assistance system.

The standard deviation of the RP, averaged by 18 trials, is shown in Fig. 12. The assistance system also suppresses the standard deviation of the RP with a significant difference under the 1% confidential level.

These effects can be seen in the minimum value of the TTC to the preceding vehicle as shown in Fig. 13. The assistance system increases the minimum value with a significant difference under the 1% confidential level and realizes the safety driving to the preceding vehicle.
3.2.3. Fuel economy

The fuel consumption is also calculated based on the fuel consumption rate map in the software(10) as shown in Fig. 14. The output of the engine this study uses is 150kW, and the density of the gasoline is 0.77kg/l.

Figure 15 illustrates the fuel economy of the following vehicle. The assistance system suppresses the fuel economy with a significant difference under the 1% confidential level.

The proposed assistance system improves not only safety to the preceding vehicle, but also fuel economy of the following vehicle.

4. Conclusion

This study proposes a system to assist an appropriate longitudinal driving by considering information not only on the preceding vehicle but also on the pre-preceding vehicle. The driving simulator experiments are carried out to investigate the effects of the assistance system, which indicates the proposed evaluation index, on the driving behavior.

The driving simulator experiments revealed that indicating the PRE3 reduces the unnecessary acceleration and deceleration to minimize the unexpected deterioration of traveling speed. The change of the RP is also suppressed, and the assistance system makes it possible to suppress the collision risk to the preceding vehicle. In addition, indicating the PRE3 also reduces the fuel consumption of the following vehicle.

This study assumes that a vehicle is equipped with some special state-of-the-art technologies that directly measures the quantity of state of the pre-preceding vehicle(7). The inter-vehicle communication can be a solution to realize the assistance system considering the pre-preceding vehicle(11). In addition, if the intermediate (the preceding) vehicle among three cars directly measures the relative states with its forward (the pre-preceding) and backward (the following) vehicles, the sensing problem can be solved by indicating the evaluation index at the rear-end of the intermediate vehicle(12).

References

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