Changes of Driver Behavior by Rear-end Collision Prevention Support System in Poor Visibility

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ABSTRACT: Changes of driver behavior by the rear-end collision prevention support system with road-to-vehicle communication, was evaluated on a public road. From a viewpoint of safety, “normative behavior” which the system certainly requires to a driver was defined as “deceleration behavior in a poor visibility section”, and it was compared between with-system and without-system conditions. As a result, behavioral changes of gas pedal release or speed decrease were observed in a part of participants. By analysis of driver’s individual characteristics, the result of behavioral changes could be interpreted as being due to driver’s situation awareness for the risk of “invisible objects”.

KEY WORDS: (Standardized) safety, information systems, driver behavior (Free) field operational test, effectiveness evaluation, driver characteristic [C1]

1. Introduction

Safety support systems for driving, which use not only a radar or camera but road-to-vehicle communication or vehicle-to-vehicle communication, have been developed toward traffic accidents reduction. It is thought that the latter is one of the effective countermeasures against traffic accidents caused by “invisible objects”. Moreover FOTs (Field Operational Tests) have been conducted to verify its effectiveness in particular areas of US, EU and Japan. Especially, since the number of rear-end collisions is largest in Japan (1), the support system is expected to prevent rear-end collision on poor visibility roads such as a curved or arched section.

In evaluation of the effectiveness, analysis with the aspect of whether driver behavior changes to safe one by the system is required to estimate contribution to traffic accidents prevention. In Smartway project and Kanagawa DSSS (Driving Safety Support Systems) project of Japan, the effectiveness was evaluated by how much the driving speed in a test section was decreased by the system in addition to subjective evaluation by questionnaire. Results of these projects showed decrease of the average driving speed (2,3). However, its effectiveness may not be seen in some cases since a driver does not always show safe behavior which a system designer expects.

In that case, it is desirable to address system improvement and find research issues through an analysis of driver behavior from various aspects of drivers. In AIDE (Adaptive Integrated Driver-vehicle Interface) project of EU, problems of simultaneous use of FCW (Forward Collision Warning) and lane departure warning were pointed out by analysis of driver behavior in a FOT, and this analysis clarified the necessity of reduction of warning frequency (4). Meanwhile, a driving simulator is often used in the purpose of system improvement. While a driving simulator has an advantage in safety and condition control, it is pointed that driver behavior in the simulator is not always consistent with that on public roads (5). Therefore, examination of driver behavior in a FOT is also important.

However, driver behavior is affected by many external factors such as a traffic situation and the support system itself on public roads. In order to understand changes of driver behavior more precisely, it is necessary to exclude factors which may not arise from the system. Furthermore, there are individual differences in driver behavior. A way of driving or response to the support system will vary due to individual differences, which makes hard to understand driver behavior. Driver’s internal factors form individual differences of driver behavior, and his/her individual characteristics which express a unique feature and personality of a driver are included in the factors. Ishibashi et al. have reported that “driving style” which is an attitude, orientation and way of thinking for daily driving affects car following behavior at low speed (6), and “driving workload sensitivity” affects route choice preference of drivers (7). Additionally in ACAS (Automotive Collision Avoidance System) FOT of US, the viewpoint of individual characteristics was introduced into acceptance evaluation of FCW and adaptive cruise control to identify the causes of the variation by individual differences (8). In light of these previous study, understanding of the individual differences of driver behavior based on driver’s individual characteristics is useful for linking evaluation results to system improvement. From these reasons, in order to understand driver behavior to the support system, it is required to confirm changes of driver behavior with excluding the factors which may not arise from the system, and to examine driver behavior from the viewpoint of individual characteristics. In this study, toward evaluation of
effectiveness of the rear-end collision prevention support system, we addressed understanding of driver behavior in DSSS-FOT of Hiroshima.

2. Outline of rear-end collision prevention support system

This system prompts a driver who is approaching to a poor visibility section such as an arched bridge to decelerate early by providing information about standing or low-speed vehicles ahead. The system is aimed at prevention of a rear-end collision to a forward vehicle due to delayed cognition in poor visibility. Functions of the system are to detect vehicles stopping for a red light at an intersection on a far side of the arched bridge by roadside camera sensor, and to transmit information about detected vehicles to approaching vehicles via road-to-vehicle communication of 5.8GHz DSRC (Dedicated Short Range Communication). In the vehicle which received the information, the driver is alerted by a vocal message and graphics on a navigation display when the system judges that vehicles are standing at a position which a driver is hard to see from the top of the arched bridge. Activation of the alert is judged by the following expression.

\[ L \geq (R_s - \Delta L_v) - \frac{V^2}{2\alpha} - V(T_r + T_d) \]  

Here \( L \) is a position of a host vehicle from an infrared-beacon (IR-beacon), \( R_s \) is the distance from the IR-beacon to the beginning point of detected area by roadside sensor, \( \Delta L_v \) is a detection error of a host vehicle position, \( V \) is host vehicle’s speed, \( \alpha \) is mean deceleration, \( T_r \) is driver’s response time for the alert, \( T_d \) is system process time.

Even though the expression (1) is met, the alert does not work in the cases where standing vehicles are not detected, the row of standing vehicles extends to nearby the top of the bridge, and host vehicle’s speed is under 20km/h at an alerting point.

The system is designed for prompting a driver to show appropriate behavior in an early stage of risk avoidance. If a driver does not show appropriate behavior, an accident risk increases. Therefore, “normative behavior” which a driver is expected to behave by the alert is assumed. As a driver is driving without the alert system usually, whether the system brings expected behavior can be the evaluation criteria of the effectiveness. Thus we expressed the “normative behavior” by combination of measures such as vehicle motion, position, and driver’s operation. Since beginning of system popularization should be simulated, we examined changes of those behaviors from baseline (i.e. driving without the alert system) to “alert condition” (i.e. driving with the alert system).

The rear-end collision prevention support system provides the alert about an invisible intersection ahead hidden by an arch. It is expected that a driver shows safe behavior without seeing far side of the arched bridge. Since the poor visibility section continues from an alerting point to the top of the bridge, we defined the “normative behavior” as taking deceleration behavior in this section. The deceleration behavior includes a gas pedal operation, a brake pedal operation, and a speed change. Especially in this test, a driver can decelerate by gas pedal release due to driving in an uphill section. Since many participants were adjusting vehicle speed by a gas pedal, we focused on a gas pedal operation and a speed change. So the indices of the “normative behavior” consisted of the following: i) rate of total time (time-rate) of gas pedal release, ii) speed difference between the alerting point and the bridge top.

3.1.2. Excluding of “noise” factors

Many factors of a traffic situation affect driver behavior. In order to extract deceleration behavior by the alert, it is necessary to exclude factors which may not arise from the system (i.e. noise). So the factors which may provoke deceleration behavior were defined by observation of traffic on the experiment site, and shown in Table 1.

Table 1 Factors provoking deceleration behavior except the alert

<table>
<thead>
<tr>
<th>Factors provoking deceleration behavior</th>
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<td>Speed adjustment for over speed</td>
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<tr>
<td>Shortening of time-headway to leading vehicle</td>
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<tr>
<td>Appearance of vehicle from side road</td>
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<tr>
<td>Brake lamp lighting of leading ahead</td>
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<td>Lane changing vehicle from adjacent lane</td>
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<td>Motorcycle in front of equipped vehicle</td>
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Of these factors, “speed adjustment for over speed” and “shortening of time-headway to leading vehicle” require to decide numerical thresholds. It is proper that these thresholds are decided based on a traffic flow, so we measured the traffic flow in the experiment section. Six drivers drove in the section along the traffic flow several times. Host vehicle’s speed, headway distance and relative velocity were sampled every 0.5m. Distributions of speed and time-headway based on sampled data are shown in Figure 2.

The threshold of “speed adjustment for over speed” was defined as the speed of 90%ile’s value of the traffic flow from the idea to exclude the cases of unusual speed. From Figure 2, the
threshold was 55km/h. Namely, even if deceleration behavior was observed over 55km/h, it was assumed by speed adjustment due to over speed. As for the threshold of “shortening of time-headway to leading vehicle”, the representative value of the distribution of time-headway was used. This value was 3 seconds which was defined by median of the distribution in the experiment site. From the fact that safe time-headway is at least from 2 to 3 seconds, this value was likely to be reasonable. And when time-headway was less than 3 seconds at the start of deceleration, the cause of the deceleration seemed to be shortening of time-headway to leading vehicle. Thus these thresholds were used to exclude noise data.

![Speed Distribution](image1)

**Fig. 2 Traffic flow in the experimental section**

3.1.3. Driver individual characteristic

In order to figure out driver individual characteristics, driving style and risk-taking tendency were investigated by questionnaires in addition to gender, age, a driving experience and so on. Driving style is an attitude, orientation and way of thinking for driving, which is thought to have a relationship to driver behavior (7). To evaluate the driving style, “Driving Style Questionnaire (DSQ)” was used. DSQ has 8 scales such as “impatience in driving”, “methodical driving” and so on. Risk-taking tendency is a tendency to take a merit in spite of a risk (8). In order to measure risk-taking tendency, a probability of taking risky behavior and degree of the behavior’s risk were scored from 0 to 100 in three situations, namely “daily life situation”, “traffic situation (except driving)” and “driving situation”.

3.2. Experiment method

3.2.1. Participants

30 employees (average age: 42.7, SD: 8.9) in R&D division of an automobile manufacturer participated in the experiment. All participants were not in charge of development of this system directly. Their average driving experience was 21.3 years. Their annual mileage ranged between about 5,000 and 10,000 km. Following matters were explained to the participants in written and oral; a content of the experiment, an outline of the system, a right to abort the experiment, protection of privacy and so on. An informed consent of every participant was given in written.

![Procedure Flow](image2)

**Fig. 3 Analysis section of driver behavior**

3.2.2. Procedure

A mini-van type vehicle (displacement: 2,300cc) equipped with the system was used for the experiment. First, the participants drove on a predetermined course around the arched bridge in order to familiarize themselves with the equipped vehicle and the experiment course. Then they drove in a condition without the alert (3 trials, as baseline) followed by a condition with the alert (4 to 7 trials). An experimenter rode the equipped vehicle together, and gave the route guidance to the driver. Considering a condition control, places and contents of the route guidance were unified and minimized. After the experiment drive, the participants completed the questionnaires for driver characteristics.

Data of vehicle motion, driver’s operation and alert output were sampled by an on-board measurement system at the 10 Hz rate. Forward video image was logged by an on-board camera at 30 frames per second.

3.3. Analysis method

In this system, since it is expected that a driver shows safe behavior to “invisible object” beforehand, it is important to evaluate behavioral changes between the alerting point and the point where the driver became able to see the tail end of standing vehicle. For this reason, the analysis section was defined as follows.

**Start point:** the alerting point (in baseline condition, the point was calculated by expression (1))

**End point:** the top of the bridge (140m from IR-beacon)

The trial in which the alert system worked first time was used in the analysis of the alert condition. In the baseline condition, the trial which had a similar traffic situation to the alert condition was
selected for the analysis. The data which had lacks or pronounced difference between the conditions were excluded from the analysis.

4. Result

4.1. Result of behavioral analysis

4.1.1. Index of gas pedal release

Data of 22 participants were valid after excluding inappropriate data. In order to identify the gas pedal release caused by noise factors in all release operations, the traffic situation just prior to a release operation was analyzed by on-board video images, road-side cameras and driver behavior data. Time-rate of gas pedal release in the analysis section was calculated in each condition after excluding the release operations caused by noise factors. First, in order to find an outline of changes of the operation, mean of time-rate of all participants was compared between the conditions. The result is shown in Figure 4. The time-rate in the alert condition increased 3 points relative to the baseline. However, there was no significant difference and the behaviors among the drivers varied widely. A cause of its variation will be an individual difference since external factors which affected driver behavior were excluded.

To examine the individual difference, changes of driver behavior within participants were classified. Here, if time-rate of gas pedal release is equal to 0%, the behavior was labeled as "gas pedal not released", and if time-rate is over 0%, the behavior was labeled as "gas pedal released". The result of change patterns, which were classified by gas pedal release in the alert condition relative to the baseline, is shown in Figure 5. 27% of the drivers showed changes to gas pedal release in the alert condition compared to the baseline. In these drivers, it seems that the normative behavior appeared by the alert, and thereby the behavior was changed to safe one.

4.1.2. Index of speed difference

In analysis with speed difference, if deceleration behavior occurs, it may affect the speed in the whole of the analysis section. Therefore, in the case that any deceleration behaviors by noise factors were involved in the analysis section, the trail itself was excluded from the analysis. As a result of the exclusion, data of 10 participants were valid. A speed difference between the alert point and the bridge top was calculated in each condition. First, mean of speed difference of all participants was compared between the conditions. The result is shown in Figure 6. In the baseline condition, the speed was averagely on the increase toward the top of the bridge, while the speed in the alert condition was decreasing. Meanwhile, there was no significant difference between the conditions, and thereby it will be from the variation...
of individual behaviors.

As with the index of gas pedal release, changes of driver behavior within participants were classified to examine the individual difference. Here, if the speed is increasing at the top of the bridge compared to the alert point (including equal), the behavior was labeled as “speed difference is plus”, and if the speed is decreasing, the behavior was labeled as “speed difference is minus”. The result of change patterns, which were classified by speed difference in the alert condition relative to the baseline, is shown in Figure 7. 50% of the drivers were changed from “plus” to “minus” by the alert. In the drivers of this group, it seems that the normative behavior appeared by the alert, and thereby the behavior probably became safer.

4.2. Driver individual characteristics between groups

From the analysis of behavioral changes within drivers, it can be seen that the drivers in which the normative behavior appeared by the alert and the drivers in which the normative behavior did not appear existed. In order to analyze the difference of behavioral changes, driver’s individual characteristics in each group was examined. Both in the index of gas pedal release and speed difference, the participants were separated into two groups: a group in which the normative behavior appeared (i.e. group “normative”) and the other group (i.e. group “other”). Then the driving style and risk-taking tendency were compared between the groups. The result of gas pedal release is shown in Figure 8 and that of speed difference is shown in Figure 9.

A significant difference of each scale score between the two groups was checked by none-paired t-test with 10% significance level. In the index of gas pedal release, “preparatory maneuvers at traffic signal” of the driving style in the group “normative” was significantly low, while there was no significant difference in the risk-taking tendency. Meanwhile in the index of speed difference, “risk estimation in driving scene” of the risk-taking tendency in the group “normative” was significantly low, while there was no significant difference in the driving style.

Fig. 8 Comparison of driver characteristics by behavioral changes of “gas pedal release” index

Fig. 9 Comparison of driver characteristics by behavioral changes of “speed difference” index
5. Discussion

When the driver’s individual characteristic of each behavioral index was compared between the groups, the significant differences were found in different scales of each index. We discuss this result as following.

Since the group “normative” in the “gas pedal release” index had a lower tendency of “preparatory maneuvers at traffic signal”, they tended to be less conscious of front situations such as a traffic signal when driving. For this reason, it is likely that the alert automatically provoked gas pedal release. As for the “speed difference” index, the group “normative” had a lower tendency of “risk estimation in driving scene”, and the group “other” had a higher tendency. According to this result, it is probable that the behavior of the latter was independent of the alert due to appropriate estimation of the risk whereas the former was led to decrease of vehicle speed by the risk awareness by the alert.

Initially, the driver’s characteristic scales which relate to deceleration behavior would be same in both indices, nevertheless the result was different. In order to examine this reason, a relationship between the two behavioral indices was analyzed. As a result of the analysis, one of five drivers in the group “normative” of the “speed difference” index showed gas pedal release, and one of six drivers in the group “normative” of the “gas pedal release” index decreased the speed difference. Therefore, the two indices were not necessarily identical.

From this result, while the group which reduced vehicle speed by the alert may think that the substantial risk could be avoided without releasing the gas pedal, the group which released the gas pedal may take no account of the relationship between the alert and the risk. It is suggested that the situation awareness on prediction of a facing risk was formed by the alert in the group which reduced vehicle speed, and that the group which released the gas pedal behaved with insufficient understanding of the situation.

In order to verify the validity of above-mentioned consideration, after participants were separated into the group “normative” and the group “other” in the index of “gas pedal release” and “speed difference”, differences of user acceptance between the two groups were examined. The user acceptance was evaluated by following items from the view point of effectiveness and value of system; (a) degree of contribution to safety driving, (b) degree of satisfaction with the system, (c) willingness to use the system and (d) monetary consideration for the system. (a), (b) and (c) were rated on a 5-point scale. (d) was given by amount of money in figures. The result of mean and standard deviation of every question which was calculated in each group is shown in Figure 10. When a significant difference between the groups was checked by none-paired t-test or Welch test with 10% significance level, the group “normative” of the “speed difference” index was significantly higher than the group “other” in the score of (a), (b) and (c), that is, this group evaluated the effectiveness and value highly. By contrast, there was no significant difference in the “gas pedal release” index. This result can be interpreted as follows: the group which reduced vehicle speed by the alert would recognize the risk of “invisible objects” and would show the substantial risk-avoidance behavior, and realizing these processes may lead to high value of the system. With thinking like this, the result of the user acceptance can be collateral evidence of above-mentioned consideration. From the above, it is indicated that not to provoke deceleration behavior automatically by the alert, but to recognize a risk appropriately will bring the high system value. Especially, for the safety driving support information on “invisible objects” like this system, it seems that the difference of the situation awareness among drivers will be easy to occur, and to construct HMI (Human-machine Interface) of the safety information in consideration of this kind of the difference is one of the future works so as to improve effectiveness and value of the system.

![Graph](image)

Fig. 10 Score of subjective evaluation for system value

6. Conclusion

Thus, we addressed analysis of driver behavior toward evaluation of the effectiveness of the rear-end collision prevention support system on a public road. As a result;

-After driver behaviors which were affected by the noise factors were identified by measurement of the traffic flow in the experimental site and observation of traffic environment, it became possible to analyze changes of the behaviors only by the alert.

-Changes of driver behavior by the alert could be interpreted by comparison of driver’s individual characteristics of two groups: one was the drivers who showed normative behavior by the alert, the other was not.

-From those analyses, we found that the research issue toward system improvement is to develop the HMI of the safety driving support system in the light of the difference of driver’s situation awareness.

After the evaluation method was systematized in the other study (10) based on some cases of the system evaluation, the effectiveness of Hiroshima DSSS was investigated with that method in large-scale FOT which was conducted by 40 cars for 6 months (11).
This study has been conducted in DSSS regional verification tests which were promoted by Universal Traffic management Society of Japan.

References