Evaluation of Acceptability of Adaptive Proactive Braking Intervention System Based on Risk Map for Elderly Drivers

Takuma Ito 1)    Masatsugu Soya 1)    Kyoichi Tohriyama 2)    Yuichi Saito 3)    Tsukasa Shimizu 4)
Akito Yamasaki 5)    Masao Nagai 6)    Hideo Inoue 7)    Minoru Kamata 1)

1) The University of Tokyo
7-3-1 Hongo, Bunkyo, Tokyo, 113-8656, Japan (E-mail: ito.t@hnl.t.u-tokyo.ac.jp)
2) Toyota Motor Corporation
1-4-18 Koraku, Bunkyo, Tokyo, 112-8701, Japan
3) Tokyo University of Agriculture and Technology
2-24-16 Nakacho, Koganei, Tokyo 184-8588, Japan
4) Toyota Central R&D Labs.
41-1 Yokomichi, Nagakute, Aichi 480-1192, Japan
5) Meijo University
1-501 Shiogamaguchi, Tenpaku, Nagoya, Aichi 468-8502, Japan
6) Japan Automotive Research Institute
2530 Karima, Tsukuba, Ibaraki 305-0822, Japan
7) Kanagawa Institute of Technology
1030 Shimo-ogino, Atsugi, Kanagawa 243-0292, Japan

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ABSTRACT: This study aims to confirm the usefulness of adaptation of proactive braking intervention systems to the risk level of the driving environment for improving the reactive factors of acceptability. First, we develop prototypes of adaptive proactive braking intervention systems around non-signalized intersections on community roads. Then, to confirm the effectiveness of adaptation, we conduct user tests, in which 45 elderly drivers participate, on public roads. From comparisons between constant setting and adaptive setting, we confirm that the adaptive setting improves the reactive factors of acceptability, such as reduction in the feeling of impatience and strangeness.

KEY WORDS: Safety, Protection of older people, Driving support/ Intelligent vehicle, Acceptability, Digital map [C1]

1. Introduction

With the growth of aging society (1), traffic accidents caused by elderly drivers have become one of the social problems in Japan (2). Because the aging ratio is estimated to continue to increase for a while, countermeasures to prevent such traffic accidents are desired. Given this motivation, our project (3) started developing autonomous driving intelligence for supporting elderly drivers. To support daily locomotion of the elderly, prevention of traffic accidents on community roads is necessary. As the Institute for Traffic Accident Research and Data Analysis (ITARDA) (4) reported, collision accidents at non-signalized intersections are one of the typical accidents on community roads. In general, visibility around non-signalized intersections on community roads is bad due to the occlusion of roadside constructions (e.g., walls of roadside houses). Further, a pedestrian rushing out from such occluded areas sometimes results in traffic accidents. Because community roads are not usually equipped with roadside cooperative sensing systems such as the driving safety support system (DSSS) (5), anticipation of an imaginary pedestrian behind occluded areas is the key for preventing traffic accidents on community roads. Based on this concept, Saito et al. (6) developed proactive braking intervention systems that anticipated a pedestrian rushing out from occluded areas around blind intersections.

In parallel with the development of the motion control algorithm, we started to evaluate the acceptability of systems that had the concept of proactive braking intervention. First, we implemented similar systems into a driving simulator (7), and evaluated the acceptability through user tests. Next, we also implemented a similar system into an actual experimental vehicle (8), and conducted the user test on a private test course. After that, we implemented Saito’s system into the experimental vehicle, and conducted the field operation test on public roads (9). In these evaluations of acceptability, we focused on the desire to introduce the system into one’s own vehicle, considering three fundamental factors: reactive factors (e.g., feelings of strangeness and impatience), comprehensive factors (e.g., expected effect for preventing traffic accidents), and reflective factors (e.g., self-image as the owner of a driving support system). The results of the abovementioned experiments showed the following common tendencies:

- The experimental participants essentially accepted the proactive braking system as a whole. Many of them answered that they wanted to introduce the examined system into their own vehicle.
- As a reason of acceptance, the experimental participants gave positive evaluations for comprehensive factors, which were the main sources for the desire to introduce the system.
Regarding the reactive factors of the system, some participants gave negative evaluations.

As for the reactive factors, because we adopted the constant assumption regarding parameters describing the behaviors of an imaginary pedestrian in our previous experiments, the system exhibited constant behaviors independently of the situations. These constant behaviors of the system might result in negative evaluations with respect to the reactive factors. Thus, the system is desired to behave adaptively, depending on the risk level of driving situations for improving these points. Therefore, in this study, we aimed to confirm the usefulness of the concept of an adaptive proactive braking intervention system.

The remainder of this paper is organized as follows. Chapter 2 describes the system design of the adaptive system. The experiment for evaluation is described in chapter 3. The results and discussions are described in chapter 4. Finally, chapter 5 gives the conclusion and describes future work.

2. Proactive Braking Intervention System

2.1. Behavior of Proactive Braking Intervention System around Target Situation

Figure 1 shows the conceptual schematic of the target situation. The longitudinal position of the vehicle, which we call “offset” in our digital map system (10), is expressed as driving distance along the road. The motion control system developed by Saito et al. (6) assumes an imaginary pedestrian, the situation of which is described by two assumed parameters: \(D_p\) and \(V_p\). \(D_p\) denotes an assumed distance between the pedestrian and a wall. \(V_p\) denotes an assumed walking speed of the pedestrian. Based on these assumed parameters and other observable parameters, the system calculates a reference velocity \(V_{min}\) that is necessary for the vehicle to avoid the collision with consideration of the additional emergent brake. Figure 2 shows a conceptual schematic of the velocity profile by proactive braking intervention. The horizontal axis indicates offset. The vertical axis of the upper graph indicates the velocity, whereas that of the lower one indicates the target deceleration value calculated by the system. The blue line of the upper graph indicates the velocity profile, whereas the red line indicates the \(V_{min}\) based on a certain combination of \(D_p\) and \(V_p\). If the velocity of the vehicle is greater than \(V_{min}\) around a blind intersection, the system intervenes in the braking control for decelerating to \(V_{min}\) in front of an intersection entrance. The end position of the braking intervention is set slightly in front of the intersection entrance because the vehicle can observe the pedestrian, if exists, at the position. During the intervention by the system, the system ignores the acceleration operation of the driver. After passing the end position of the braking intervention, the driver’s acceleration operation is allowed, as shown in the Fig. 2. Although the details of the formulations and other variables were described in the previous paper (6), the important point is that the reference velocity \(V_{min}\) depends on two assumed parameters describing behaviors of an imaginary pedestrian: \(D_p\) and \(V_p\).

2.2. Concept Design of Adaptive Motion Control Based on Map-based Risk Information

To make the proactive systems more adaptive to the driving situations, we need to introduce the adaptive assumption parameters based on risk information of driving situations. On this point, there are two topics to be discussed. The first one is how to obtain risk information of driving situations, whereas the second one is how to reflect the risk information on the assumption parameters. For the first topic, we developed a risk-map generation system in our previous study (11). By a data-driven approach, we evaluated the risk of non-signalized intersections. In our method, the risk information is expressed in terms of three discretized levels: low, medium, and high. The details of the risk-map generation system are given in our previous paper (11).

On the contrary, for the second topic, we need to consider the relation between map-based risk information and assumption parameters for motion controls. For this point, we focused on the analysis of the near-crash incidents by Ogiwara et al. (12). They analyzed the actual behaviors of the pedestrian rushing out from occluded areas, which were our target situations in this study. They extracted 109 samples of high-level data from the near-crash incident database, and estimated the time-series trajectories of the pedestrians. Then, they made histograms of three parameters: initial walking position \(Y_{p0}\), walking velocity \(V_p\), and angle of walking \(\theta_p\). Among these parameters, \(Y_{p0}\) defined by Ogiwara et al. is equivalent to \(D_p\) defined by Saito et al. In addition, the \(V_p\) defined by both groups are almost equivalent to each other. Because such real-world data is beneficial for discussing the parameters of motion control systems, we used their histograms as a reference.

2.3. Reference Velocity Based on Various Assumption Parameters

First, we estimated the percentile values of \(D_p\) and \(V_p\) based on the histograms analyzed by Ogiwara et al. Because the detailed distributions were not clear in Ogiwara’s paper, we assumed a first-order approximation that the data in a certain bin were equally distributed in the range of the bin. Figures 3 and 4 show...
the estimated results. For both parameters, less percentile values indicate safer situations. For example, in the case of 30 percentile values, the distance between a wall and a pedestrian is approximately 3.7 m, and the walking speed of the pedestrian is approximately 4.9 km/h. Although there might be a relation between these parameters, it was not described in their paper. Thus, as a first step, we assumed that these parameters were independent of each other.

![Fig. 3 Estimated percentile values of Dp.](image1)

![Fig. 4 Estimated percentile values of Vp.](image2)

Next, we calculated Vmin, which is the necessary reference velocity, for various cases. Figure 5 shows the reference velocity based on various percentile values of Dp and Vp. For example, in the case of 30 percentile values, if the vehicle slows down to approximately 30 km/h by proactive braking, it can avoid collision with a pedestrian by an additional emergency brake. Because the velocity of the vehicle is usually limited under 30 km/h on community roads in Japan, assumption parameters more than 30 percentile values appear effective for our target situations.

![Fig. 5 Reference velocity based on various percentile values of Dp and Vp.](image3)

2.4. Association between Map-based Risk Information and Assumption Parameters

Regarding the relation between the map-based risk information and percentile values of assumption parameters describing behaviors of an imaginary pedestrian, precise association is a difficult problem. However, the main purpose of this research is not parameter study but the confirmation of usefulness of the adaptive proactive braking concept. Thus, as a first step, we focused on the conditions based on the quartile percentile values in the effective range. Specifically, because the effective range was more than 30 percentile, the first, second, and third quartile percentile values are 47.5 percentile, 65.0 percentile, and 82.5 percentile, respectively. As a basic condition of adaptive proactive braking intervention systems, we associated these percentile conditions with low, medium, and high risk levels, respectively. We call this setting as “adaptive setting 1.” Table 1 lists the relation between map-based risk information and corresponding Vmin. For example, if the digital map considers the risk level of a certain intersection as high, the proactive braking intervention system decelerates to approximately 11.7 km/h. To confirm the usefulness of such an adaptive system, we needed to compare it with the non-adaptive one. Thus, as a comparison target, we prepared the constant setting that used the assumption parameters of 82.5 percentile for all risk levels. This means that the system with constant setting always assumes the risk level of intersections as high. Additionally, in adaptive setting 1, not only the adaptive characteristics but also average increase of Vmin as a whole might affect the acceptability. In other words, if drivers prefer the adaptive setting 1, we cannot judge whether it results from the adaptive characteristics or average increase of Vmin. Thus, to obtain the reference comparison, we prepared another adaptive setting that slowed the vehicle down more than adaptive setting 1. Specifically, we assumed additional 10 percentile situations from adaptive setting 1. We call this setting as adaptive setting 2, and Table 1 summarizes the details.

| Map-based risk information | Adaptive setting 1 | Constant setting | Adaptive setting 2 |
|---------------------------|-------------------|-----------------|--------------------|
| Assumed percentile Vmin   | Assumed percentile | Assumed percentile | Assumed percentile |
| High                      | 82.5              | 11.7            | 92.5               |
| Medium                    | 65.0              | 19.1            | 75.0               |
| Low                       | 47.5              | 23.8            | 57.5               |

3. Experiment

To evaluate the adaptive proactive braking intervention system, we conducted experiments using an actual experimental vehicle on public roads. The following protocol was approved by the Institutional Review Board for human studies of the University of Tokyo. We explained the protocol of the experiment to the participants and obtained their consent.

3.1. Participants

In this study, we recruited 45 elderly drivers as experimental participants. To be more precise, 38 male drivers and 7 female drivers participated in the experiment. The participants lived in Kashiwa city where the experimental course existed. Their average age was 72.9 years (SD = 3.7 years), they had driving licenses for 44.7 years on average (SD = 11.3 years), and their average driving frequency was 4.1 days per week.

3.2. Experimental Vehicle

Figure 6 shows the appearance of the experimental vehicle. This vehicle was equipped with a digital map system and could determine the relative distance to the intersections. Additionally, we implemented the proposed motion control system into this vehicle. Thus, this vehicle could execute adaptive proactive braking intervention near the blind intersections. Regarding the lateral control, because the system was incapable of maneuvering, the participants maneuvered the steering wheel by themselves.
3.3. Experimental Course

The experiment was conducted from October 29th, 2018 to November 20th, 2018. Additionally, it was conducted from 9 AM to 4 PM. Thus, it was basically conducted in the bright daytime. Figure 7 illustrates the route map of the experimental course. This figure is based on the map images published by Geospatial Information Authority of Japan (13). The orange areas indicate the positions of buildings such as houses. As can be seen in the figure, all parts of the experimental course were community roads. Thus, the vehicle velocity was limited to 30 km/h. Additionally, because there were few other traffic participants in this course, interactions with other traffic participants basically did not happen. Furthermore, in the case when the interactions that might have some effects to the drivers’ operations happened around the target intersections, we conducted the trial again although such cases were rare.

In this course, we set six intersections where the proactive braking intervention system was operated. The red circles from I1 to I6 indicate the target intersections. Table 2 presents the estimated risk levels of the intersections. These settings were determined by referring the results of the previous study (11). Although the risk levels were estimated by a data-driven approach, the types of intersections advocate the estimation results. For example, because the intersections I3 and I4 are blind crossings, there is a possibility of pedestrians rushing out from either side. Regarding the rest, intersections I2, I5, and I6 are blind T-junctions from right side of the road. Because the vehicles drive on the left side of the road in Japan in contrast to many other countries, the visibility around the T-junctions from the right side of the road is better than that around the T-junctions from the left side. Hence, I1 has more risk than I2, I5, and I6.

| Intersection | Estimated risk level | Type of intersection |
|--------------|----------------------|----------------------|
| I1           | Medium               | Blind T-junction from left |
| I2           | Low                  | Blind T-junction from right |
| I3           | High                 | Blind crossing |
| I4           | High                 | Blind T-junction from right |
| I5           | Low                  | Blind T-junction from right |
| I6           | Low                  | Blind T-junction from right |

Figures 8, 9, and 10 show examples of velocity profiles at I1, the estimated risk of which is medium, for constant setting, adaptive setting 1, and adaptive setting 2, respectively. The $V_{\text{min}}$ for medium risk of each setting is 11.7 km/h, 19.1 km/h, and 16.0 km/h, respectively. In accordance with each $V_{\text{min}}$, the target deceleration values vary, as shown in the Figs.
In addition to the target intersections, the system automatically decelerates at the intersections where the vehicle turns right. These intersections are indicated by the green circles in Fig. 7. We formulated this setting for the following reasons: to conduct the experiments safely and to ensure consistency with the functions at the target situations. However, because we focused on acceptability of the proactive braking intervention at the intersections where the vehicle drove through straightforwardly, we instructed the participants not to evaluate the system behavior around the intersections where the vehicle turned right.

3.4. Experimental Order

Figure 11 shows the flow of the experimental order. In the first session, the participants experienced manual driving to get themselves adjusted to the experimental course. In the second session, the participants experienced shared driving with the system to adjust themselves to the proactive braking intervention. Because there were three settings in this session, the participants drove thrice. The order of the settings in this session was randomized. The second session was conducted to make the participants acquire a basis for evaluation. In the third session, the participants experienced shared driving again for evaluating the proactive braking intervention. The order of the settings in this session was the same as that in the second session. For each setting, the participants drove twice continuously. After the second trip of each setting, the participants answered the questionnaire.

1\textsuperscript{st} session: Manual driving once to adjust to the experimental course.

2\textsuperscript{nd} session: Shared driving with the system once to adjust to the proactive braking intervention.

2a. Constant setting (once)
2b. Adaptive setting 1 (once)
2c. Adaptive setting 2 (once)

Order of the settings was randomized.

3\textsuperscript{rd} session: Shared driving with the system twice to evaluate the proactive braking intervention.

3a. Constant setting (twice)
3b. Adaptive setting 1 (twice)
3c. Adaptive setting 2 (twice)

Order of the settings was the same as that in the 2nd session.

Fig. 11 Flow of experimental order.

3.5. Instructions

We gave the following instructions to the participants before the experiment.

- The participants will experience the braking support system at the potentially dangerous intersections where pedestrians or vehicles might rush out from the occluded area.
- The system’s function is not autonomous driving but only providing driving support to the participants. Thus, braking operations by the participants are also necessary.
- Drive as usual, even in the condition of shared driving. Do not intentionally change the driving style to prevent the system from executing proactive braking intervention.
- Although the system proactively decelerates at some intersections where the vehicle turns right, the system behavior around these intersections are the same for each setting. Therefore, in the evaluation, do not consider the behaviors around such intersections.
- Do not change the basis of evaluation during the third session.

3.6. Evaluation Method

Based on the findings of our previous studies \(^{(7)(8)(9)}\), we evaluated the acceptability of the proposed system using the following questionnaire.

A. Reactive factor

- “To what extent did you feel that the system’s deceleration was adequate for the situation?”
- “To what extent did you feel impatience during the system’s intervention?”
- “To what extent did you feel strangeness comparing with your driving?”

B. Comprehensive factor

- “To what extent do you feel that the system can reduce traffic accidents?”

C. Total evaluation

- “To what extent do you want to introduce the system into your own vehicle?”

The participants answered the questionnaire based on a grade scale of 1 to 9. The followings show the description of each grade.

Grade 1: The participants feel so.
Grade 3: The participants feel a little.
Grade 5: No opinion.
Grade 7: The participants did not feel so much.
Grade 9: The participants did not feel so.

In addition to the above questionnaire, we logged operation data by the driver and state variables of the vehicle. Although the examined system intervened the operation of the drivers, it did not work for some cases. For example, if the participants intentionally slowed down to cancel the system’s intervention, the system did not work. Moreover, if the driving style of a certain participant was sufficiently safe, the system did not work, especially at the intersections with low and medium risk levels. To investigate such cases, we analyzed the numerical driving data.
4. Experimental Results

4.1. Exclusion of Results of Invalid Participants

4.1.1. Exclusion of Participants Who Changed the Driving Style Intentionally

We considered the participants who might intentionally change their driving style between the first and third sessions. Figure 12 illustrates an example of the velocity profile of a certain participant. The blue line indicates the velocity profile under the manual driving condition in the first session, whereas the red line indicates the velocity profile under the shared driving condition in the third session. As shown in the figure, this participant did not slow down at the intersection entrance in the first session. However, in the third session, the participant actively slowed down the velocity around the intersection to prevent the system’s intervention. Indeed, the system did not output any target deceleration value around this intersection. Because this participant showed similar changes at other intersections as well, we considered this result as an intentional one. The driving results of five participants, including this example, show similar tendencies. Because these participants did not follow the experimental instructions, we excluded them from subsequent analysis.

Fig. 12 Example of change in driving behavior under the shared driving condition.

4.1.2. Exclusion of Participants Who did not Experience Adaptive Proactive Braking Intervention

For the results of the remaining 40 participants, we checked the record of proactive braking intervention by the system because the system did not intervene the braking operation for sufficiently safe drivers. Figure 13 shows the example of velocity profile where the system did not intervene the braking operation. As shown in the figure, because the vehicle’s entry velocity was originally lower than $V_{\text{min}}$, owing to the driver’s braking operation, the system did not output any target deceleration value. As a result of checking all results, we confirmed that the system did not work at the low and medium risk level intersections under the conditions of adaptive settings with regard to some participants. Table 3 lists the number of the participants who did not experience the braking intervention at the low and medium risk level intersections for each condition. Although these participants experienced braking intervention at the high risk level intersections, they could not feel the characteristics of the adaptive setting due to the lack of intervention experience at the other risk levels intersections. Thus, we excluded these participants from subsequent analysis.

Fig. 13 Example of the velocity profile where the system did not intervene the braking operation.

Table 3 Estimated risk level of each intersection.

| Intersection entrance | Adaptive setting 1 | Adaptive setting 2 |
|-----------------------|-------------------|-------------------|
| Number of excluded participants | 6                 | 2                 |
| Number of remaining participants for subsequent analysis | 34                | 38                |

4.2. Comparisons between Adaptive Setting 1 and Constant Setting

First, we compared the reactive factors between constant setting and adaptive setting 1. Figures 14, 15, and 16 illustrate the comparison results of the feelings of appropriateness, impatience, and strangeness, respectively. As for the vertical axis, a lesser grade indicates a stronger agreement to the corresponding questions. Thus, the participants felt more appropriate in the driving situation for adaptive setting 1 rather than the constant setting. On the contrary, the participants felt less impatience and strangeness for adaptive setting 1. Wilcoxon signed-rank test revealed significant differences of the results under 5% significance level. Thus, the adaptive setting 1 improved the reactive factors of the proactive braking intervention system.

Fig. 14 Comparison of feeling of appropriateness between constant setting and adaptive 1 setting.

Fig. 15 Comparison of feeling of impatience between constant setting and adaptive 1 setting.
Then, we compared the comprehensive factors between settings. Figure 17 shows the comparison results of feeling of effect for reducing traffic accidents. Similar to the above comparison, a lesser grade indicates a more agreement to the question, which implies a positive evaluation in this case. As for this comparison, we did not confirm a significant difference under 5% significance level. Although the comparison result seems to be equivalent for both settings, a detailed analysis showed that 13 participants gave improved evaluations and five participants gave worsened evaluations for adaptive setting 1. Thus, the adaptive setting caused both changes rather than maintaining the evaluation results. However, because many participants gave positive evaluations for both settings, the ceiling effect seems to have occurred, as shown in Fig. 17. Thus, there may be differences if we used another scale for the questionnaire.

Finally, we compared the total evaluation between the settings. Figure 18 shows the comparison results of desire to introduce the system into one’s own vehicle. We did not confirm a significant difference under 5% significance level. The detailed analysis showed that six participants gave improved evaluations and six participants gave worsened evaluations for adaptive setting 1. Table 4 summarizes the number of the participants who gave improved and worsened evaluations for adaptive setting 1.

4.3. Comparisons between Adaptive Setting 2 and Constant Setting

Similar to the abovementioned comparisons, we compared the factors of adaptive proactive braking intervention system between constant setting and adaptive setting 2. Figures 19, 20, 21, 22, and 23 show the comparison results of feelings of appropriateness, impatience, strangeness, effect for reducing traffic accidents, and desire to introduce the system into one’s own vehicle, respectively, between constant setting and adaptive setting 2. Table 5 lists the number of the participants who gave improved and worsened evaluations for adaptive setting 2. As shown in the table, we confirmed both improved and worsened evaluations for adaptive setting 2 although the number of improved evaluations were equal to or more than that of worsened evaluations. However, because we could not confirm significant differences of the results under 5% significance level by Wilcoxon signed-rank test, we considered the evaluation results in both settings as equivalent.
4.4. Discussion

Based on the comparison results summary, we confirmed significant differences between the constant setting and adaptive setting 1 with regard to the reactive factors of proactive braking intervention system. Specifically, we confirmed that adaptive setting 1 improved the evaluations. The reason for these improvements can be interpreted in two ways: adaptiveness of the system to the risk level of the driving situation and average increase of $V_{\text{min}}$. The comparison results between the constant setting and adaptive setting 2 are critical in analyzing these results. Because adaptive setting 2 assumed a higher risk at each intersection than adaptive setting 1, the degree of deceleration increased in adaptive setting 2. The system decelerated to approximately 6.0 km/h, which was the lowest $V_{\text{min}}$ in this study, at high risk level intersections in adaptive setting 2. This increase in the degree of deceleration could be the element that worsened the evaluation of the reactive factors. However, the comparison results between constant setting and adaptive setting 2 shows equivalent evaluations. Thus, the adaptive characteristics of the system compensated the negative effect by the average increase of deceleration. Therefore, as for the comparison results between the constant setting and adaptive setting 1, not only the average decrease of deceleration but also adaptiveness of the system improved the evaluation of the reactive factors. In short, the adaptive concept for proactive braking intervention system aided the improvement of the evaluation of reactive factors.

5. Conclusion

In this study, we aimed at confirming the usefulness of adaptation of proactive braking intervention system to the risk level of driving environment for improving the reactive factors of the acceptability. First, we implemented the adaptive system based on the existing constant setting. Then, we conducted the user evaluation test, in which 45 elderly drivers participated, on actual community roads. As a result of comparisons between constant setting and adaptive settings, we confirmed that the adaptive concept for the proactive braking intervention system aided the improvement of the evaluation of reactive factors. Improvement on these points will contribute to the future popularization of the proactive braking intervention system.

However, because we could not determine the relation between the drivers’ characteristics (e.g., smoothness-oriented and safety-oriented) and evaluation results based on the result in this study, further analysis will be necessary in a future study. Additionally, mismatch between risk evaluation by the system and subjective risk feeling perceived by safety-oriented drivers seems to be the reason for negative evaluation with regard to the adaptive settings. Thus, development of devices, such as human machine interfaces, that present risk levels to the driver for balancing the improvement of reactive factors and the maintenance of the safety feeling to prevent the mismatch is also one of the aspects of future work. Moreover, we simply associated the assumption parameters for motion control with the map-based risk information as a first step. Therefore, designing the method for detailed association will be necessary. Furthermore, the evaluation was conducted as a short term test in a limited area. Thus, long term tests on various public roads are desired for further discussions.

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