Collision Risk Assessment of Right Turns at Intersections Based on Driving Behavior for ADAS (Second Report) - Risk Assessment Method Considering Traffic Environment Difference -

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In our previous study, we proposed two driving behavior indices that can assess the risk of collision against crossing pedestrians during right turns at intersections for the driver assistance mentioned above [3]. Collision risk against pedestrians in various traffic environments need to be assessable to realize driver support in public road environment using the proposed driving behavior indices. However, the proposed driving indices have been verified only in a limited traffic environment. Furthermore, there is a possibility that the collision risk assessed by the proposed indices may differ under different traffic environments because driving is an adaptive behavior to the surroundings and other studies show that traffic environment has an influence on driving behavior [4][5]. Therefore, the objective of this research is to clarify the influence of traffic environment on the collision risk assessed with the driving behavior indices and propose a risk assessment method considering the difference in the traffic environment.

In this paper, we first describe the definition of the driving behavior indices proposed in our previous study in chapter II, and then describe the methods, including an experiment and a simulation, to clarify the influence of traffic environments in chapter III. Next, we describe the results of experiment and simulation in chapter IV. Based on the results, we propose an assessment method in chapter V. Lastly we summarize the findings in chapter VI.
II. Driving Behavior Indices for Collision Risk Assessment at Right Turns

The driving behavior indices proposed in our previous study are the curvature of the right-turn trajectory $\varphi_{cl}$ and the speed at the centerline pass timing $V_{cl}$ [3]. Both indices are calculated based on the position, heading, and speed of the right-turning vehicle when it passed the centerline of an intersection, and a target destination point near the exit of an intersection which is a point that the vehicle will reach in the near future to complete a right turn. $\varphi_{cl}$ is expressed by equation (1) in a situation shown in Fig. 1 where $\theta_{dat}$ denotes the angular deviation between the target destination point and the vehicle’s center of gravity (CoG), $D_{dat}$ denotes the distance between the target destination point and the vehicle’s CoG, and $FL_{av}$ denotes the front vehicle length from the CoG of the vehicle. $\varphi_{cl}$ indicates the distribution of visual attention and has a relation with the lapse time until a driver finds a pedestrian walking on a crosswalk. $V_{cl}$ indicates the adjustment of vehicle speed and has a relation with the margin time that a driver can find a crossing pedestrian before reaching the crosswalk. Results of a driving experiment showed that the collision risk against crossing pedestrians can be assessed with the combination of these two indices.

In our previous study, we focused on a right-turn scenario where there are no other traffic participants other than the right-turning vehicle and a crossing pedestrian at the crosswalk (a cruising right-turn scenario). This scenario is one of the three typical scenarios of near-miss incidents involving a right-turning vehicle and a crossing pedestrian at an intersection with a traffic signal [6]. Hence, we focused on the same cruising right-turn scenario in this study.

$$\varphi_{cl} = \frac{\theta_{dat}}{D_{dat} \cdot FL_{av}}$$

(1)

III. Methods

To clarify the influence of traffic environment on collision risk assessed by the driving behavior indices, first, we selected traffic environmental elements to evaluate. Next, we obtained right-turn behavior data of different traffic environment conditions using a driving simulator (DS). A DS can reproduce risk scenes such as scenes where a pedestrian rushes into a crosswalk when a driver is making a right turn, and acquire behavior data of drivers in risk scenes. However, it is difficult to acquire driving data of several different risk scenes from the same driver with the same attitude, because a driver would likely to change their attitude and behavior after experiencing a risk scene. Hence, we quantified the collision risk against pedestrians during a right turn by simulating the behavior of the driver using the behavior data acquired in the DS experiment. Finally, we compared the relationship of the driving behavior indices and collision risk between different environmental conditions. The traffic environmental elements selected, the details of the DS experiment and collision risk simulation are described in the following sections.

A. Traffic Environmental Elements

When the collision risk indicated by the driving behavior indices are affected by environmental elements, it is necessary to consider the difference due to the elements in the assessment of collision risk. To enable this with a real support system, the system needs to know about the intersection where a driver is making a right turn. A digital map database, which is already used in car navigation systems, contains information about various traffic environments. Therefore, with an eye to applying the driving behavior indices to support systems in the future, we selected the width of the entrance and exit roads of a right-turning intersection, and the crossing angle of a right-turning intersection as elements to evaluate included in the map database. Fig. 2 shows the definition of the elements. Our previous research showed that the entrance road width, exit road width, and crossing angle have significant influences on the driving behavior indices as a result of analyzing data of a naturalistic driving study [7].

B. Driving Simulator Experiment

In this experiment, we used a 4-screen DS with a field-of-view of 180 degrees (Fig. 3). Using this DS, participants performed 36 right turns in total where no other traffic participants existed at an intersection with a traffic signal after sufficient practice of the DS. We set 7 intersection conditions with different properties of the selected environmental elements as shown in Table 1, and each participant drove 5 times for each condition and a risk scene in 11 at the last. The participants were ordered to drive as they usually do. Vehicle behavior and driver operation, videos of the vehicle’s surroundings and the driver were recorded during the simulator drive. In addition, the driver’s gaze behavior and head motion were recorded using the Tobii Pro Glasses 2 (Tobii AB). The participants were 38 healthy adults with a valid driver license ($M$ age 26.7 years, $SD$ 7.4 years). The participants were thoroughly explained about the nature of the experiment beforehand and informed consent was obtained. This experiment was conducted under the approval of the ethics committee of the University of Tokyo.
C. Collision Risk Simulation using Driving Simulator Data

We simulated the collision risk against a crossing pedestrian of a right turn made at an intersection inside the virtual world of a DS by simulating the timing that the driver found a virtual crossing pedestrian and started pressing the brake pedal to avoid collision with him. In this simulation, we calculated the collision risk against a pedestrian which traveled straight at a constant speed (6 km/h) and will collide with the vehicle at the center of the crosswalk unless the driver found the pedestrian and take an action to avoid him. We supposed that the driver was not aware of the pedestrian until he/she started to make a right turn, and set that the driver was able to find the pedestrian after the commencement of a right turn (steering angle over 30 degrees to the right). In addition, the initial position of the pedestrian was determined based on the right-turn commencement timing. The virtual collision point, which the right-turning vehicle and the virtual pedestrian collides, was determined as the intersection point of the crosswalk center and the right-turn trajectory of the vehicle (Fig. 4).

The useful field of view is known to be about 4 to 20 degrees, and the peripheral vision is about 180 to 210 degrees. The pedestrian will be findable not only in the useful field of view but in the peripheral vision as well. However, the size of the visual field changes due to various factors and it is difficult to imitate the behavior of a driver with a single constant size. Therefore, we set conditions of the size of the visual field in the range of 20 to 180 degrees with a 1-degree interval and took the average of the collision risk computed from each condition of the visual field. The pedestrian was judged as found when the pedestrian was inside the set range of the visual field, the distance between the pedestrian and driver was under 50 m, and the pedestrian was not inside the blind spot made by the vehicle’s A-pillar where the pedestrian is not visible.

The timing when the driver starts to press the brake pedal was set to be a certain reaction time after the driver found the crossing pedestrian. In this simulation, we used the median brake reaction time 0.63 s from Makishita’s study [8]. We simulated that the vehicle will travel according to the original trajectory after the driver found the pedestrian. We adopted the time-to-collision at brake start timing \(\text{TTC}_{\text{brake}}\) as a reference measure of collision risk against crossing pedestrians. \(\text{TTC}_{\text{brake}}\) is defined as equation (2) where \(V_{\text{brake}}\) is the vehicle speed at brake start timing and \(D_{\text{brake}}\) is the distance left to the virtual collision point on the crosswalk. In this study, we assumed that \(\text{TTC}_{\text{brake}}\) shorter than 2.0 s is relatively high risk because right turns with \(\text{TTC}_{\text{brake}}\) shorter than 2.0 s had sudden and large deceleration brakes to avoid collision with a crossing pedestrian in our previous study [3].

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\text{TTC}_{\text{brake}} = \frac{D_{\text{brake}}}{V_{\text{brake}}}
\]
IV. Results

One participant was not able to finish the experiment due to simulator sickness. The calibration process of the eye tracker was not successful for two participants, and driving data of one participant was not recorded due to the malfunction of the recorder. Therefore, the data acquired for the remaining 34 participants were analyzed and used as simulation data.

If the environmental elements had an influence on the relationship between collision risk and the driving behavior indices, the distribution of the driving behavior indices of high-risk driving data is assumed to be different among the intersection conditions. Therefore, we investigated the difference in the distribution of $\phi_{cl}$ and $V_{cl}$ among different intersection conditions of driving data with high risk ($TTC_{brake}$ shorter than 2.0 s) to evaluate the influence of traffic environmental elements on collision risk. Each figure of Fig. 5 is comparing the intersection conditions between different entrance road widths (Fig. 5(a)), exit road widths (Fig. 5(b)), and crossing angles (Fig. 5(c)). The results showed that the distribution of the indices of high-risk driving differed between the different conditions. When the widths of the entrance and exit roads were narrower and the crossing angle of the intersection was smaller and acute, high-risk driving existed in areas where $\phi_{cl}$ was larger and $V_{cl}$ was lower. In addition, $\phi_{cl}$ was smaller and $V_{cl}$ was higher when the road width was wider and the crossing angle was larger and obtuse. From this, it could be said that the road width and the crossing angle have influences on the relationship between collision risk and the driving behavior indices.

![Fig. 5: Comparison of driving behavior indices of high-risk driving between different intersection conditions](image)

**Notes**
- I2: Road width 5.5 m with no centerline
- I1: Road width 7.0 m with 1 lane on each side
- I3: Road width 14 m with 2 lanes on each side
- I4: Road width 5.5 m with no centerline
- I1: Road width 7.0 m with 1 lane on each side
- I5: Road width 14 m with 2 lanes on each side
- I6: Acute ($\alpha = 60^\circ$)
- I1: Right ($\alpha = 90^\circ$)
- I7: Obtuse ($\alpha = 120^\circ$)
To clarify the influence of environmental elements on the relationship between the driving behavior indices and collision risk, we investigated the difference in the relationship between the driving behavior indices and factors related to collision risk: \( T_{\text{lapse}} \) and \( T_{\text{margin}} \). \( T_{\text{lapse}} \) is the lapse time until the driver found the crossing pedestrian after he appeared, and \( T_{\text{margin}} \) is the margin time that the driver can search for and find the pedestrian, which can be defined as the time duration from commencement of steering to arrival at the crosswalk in our simulation. Collision risk is assumed to be related to the remaining time to reach the crosswalk after the driver found the pedestrian, which will be expressed as \( T_{\text{margin}} - T_{\text{lapse}} \). We investigated the relationship between \( \varphi_{cl} \) and \( T_{\text{lapse}} \), and \( V_{cl} \) and \( T_{\text{margin}} \) respectively of different intersection conditions and compared them. Fig. 6 shows a sample result of comparing the relationships between intersection conditions I1 and I2. For condition I2, \( T_{\text{lapse}} \) was shorter when \( \varphi_{cl} \) was large compared to I1, and \( T_{\text{margin}} \) was shorter when \( V_{cl} \) was low. These differences between I1 and I2 were in line with the previous result that high-risk driving existed in large \( \varphi_{cl} \) and low \( V_{cl} \) areas when the road width was narrow. Similar results were achieved from the comparisons of the relationships between other intersection conditions (I3 – I7) and I1. Therefore, it is suggested that the difference in the relationships between the driving behavior indices and the collision-risk related factors indicate the influence of traffic environment on collision risk. Moreover, considering the difference in the relationships of different environmental conditions is a solution to take the influence of traffic environment on collision risk into consideration when computing collision risk based on driving data.

Fig. 6: Comparison of the relationship between driving behavior indices and risk-related indices of I1 and I2

V. Collision Risk Assessment Method Considering the Influence of Environmental Elements

From the results of the previous chapter, we proposed an assessment method of collision risk considering the influence of traffic environment by estimating the \( T_{\text{lapse}} \) and \( T_{\text{margin}} \) based on the driving behavior indices. To derive a formula to estimate the collision risk related indices (\( \hat{T}_{\text{lapse}} \) and \( \hat{T}_{\text{margin}} \)), we first computed the median value from the data of a certain range of the driving behavior indices as shown in Fig. 7. Next, we formulated a linear regression formula of the risk-related indices using the medians to estimate them with the driving behavior indices as equation (3) and (4). Linear regression formulas were created for each intersection condition and \( i \) denotes the condition, \( a_i \), \( b_i \), \( c_i \), and \( d_i \) were constant coefficients. Collision risk is assumed to be expressed with the two risk-related indices and we defined the assessed collision risk \( CR \) as equation (5). \( CR \) is expressed with the driving behavior indices and the coefficients from the linear regression of the corresponding environmental condition.

To evaluate the effectiveness of the method, we calculated the correlation between the assessed collision risk \( CR \) and the reference collision risk \( TTC_{\text{brake}} \) (Fig. 8). The assessed collision risk showed significant and strong correlation with \( TTC_{\text{brake}} \) \((r = 0.70, p < 0.01)\). Moreover, if we used the linear regression formula of \( CR \) and \( TTC_{\text{brake}} \) with the method to adjust the degree of risk, it was possible to discriminate high \( (TTC_{\text{brake}} < 2.0 \text{ s}) \) and low risk \( (TTC_{\text{brake}} \geq 2.0 \text{ s}) \) driving data with the accuracy of approximately 80%. The results above indicated the effectiveness of the proposed assessment method of collision risk.

\[
\hat{T}_{\text{lapse}} = a_i \cdot \varphi_{cl} + b_i \tag{3}
\]

\[
\hat{T}_{\text{margin}} = c_i \cdot V_{cl} + d_i \tag{4}
\]

\[
CR = \frac{\hat{T}_{\text{margin}} - \hat{T}_{\text{lapse}}}{(c_i \cdot V_{cl} + d_i) \cdot (a_i \cdot \varphi_{cl} + b_i)} \tag{5}
\]
VI. Conclusion

To clarify the influence of traffic environment on collision risk against crossing pedestrians assessed with driving behavior indices of right turns at intersections, we conducted a DS experiment and a risk simulation using the DS driving data. In addition, we proposed an assessment method of collision risk considering the influence of environmental elements based on the results of the experiment and simulation. The followings are our conclusions:

- Widths of entrance and exit roads of an intersection and crossing angle of an intersection had an influence on collision risk assessed with the driving behavior indices. When the widths were narrower and the crossing angle was smaller and acute, there were high-risk driving in the area where $\phi_{cl}$ was larger and $V_{cl}$ was lower.
- The difference in the relationships between the driving behavior indices and the risk-related indices among the different environmental elements reflected the influence of environmental elements on collision risk.
- Assessment of collision risk considering the influence of environmental elements by estimating the risk-related indices with the driving behavior indices and linear regression formulas for specific environmental conditions was effective showing significant and strong correlation with the reference measure of collision risk.

References